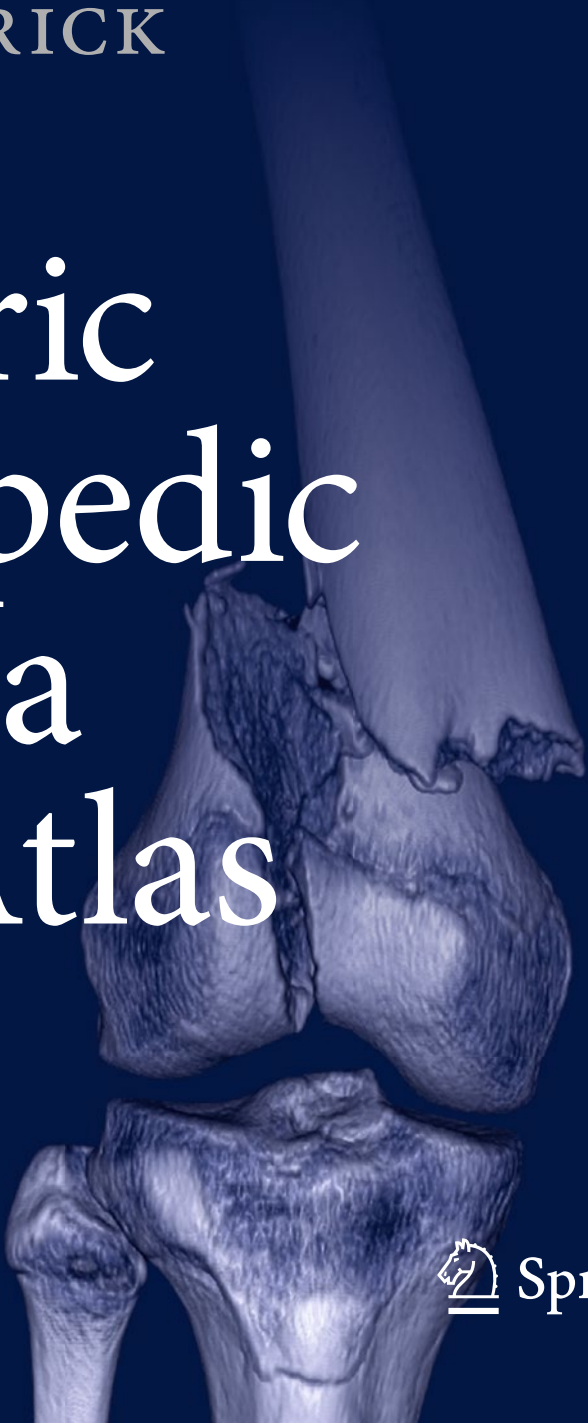


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STEVEN L. FRICK
EDITORS

Pediatric Orthopedic Trauma Case Atlas



 Springer

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Christopher A. lobst • Steven L. Frick
Editors

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With 961 Figures and 18 Tables

 Springer

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ISBN 978-3-319-29979-2 ISBN 978-3-319-29980-8 (eBook)
ISBN 978-3-319-30860-9 (print and electronic bundle)
<https://doi.org/10.1007/978-3-319-29980-8>

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This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

We are privileged to present to you the first edition of the *Pediatric Orthopedic Trauma Case Atlas*. If you scroll through the table of contents, you will notice that many of the section editors and chapter authors of this book are current or former Nemours pediatric orthopedic surgeons. By design, this textbook was originally intended to be a collective project of the entire Nemours pediatric orthopedic enterprise. However, as the scope of the project increased, we found that additional authors/editors were needed to help complete the content. Ultimately, a diverse group of expert surgeons have contributed to this text to which we are extremely grateful for their time and efforts. We would especially like to thank our colleagues at Lucile Packard Children's Hospital Stanford and Nationwide Children's Hospital for their many outstanding contributions to the book.

This book is using a unique, case-based chapter structure that we feel is an ideal educational format. It is designed to present concise and practical information to the reader about each topic. The goal is to provide state-of-the-art management tips and solutions for commonly presenting pediatric orthopedic injuries involving the extremities, pelvis, and spine. We hope that this book will be used as a resource by both the young and the experienced surgeon.

November 2019

Christopher A. Iobst, M.D.
Steven L. Frick, M.D.

Acknowledgments

Christopher A. Iobst

I would like to thank Dr. Frick for the opportunity to collaborate on this textbook. His mentorship and guidance over the years has been invaluable to me. While working together at Nemours, I had the opportunity to witness his unparalleled work ethic, professionalism, and eloquence firsthand. It is truly an honor to share this project with him.

I would also like to thank my family (Nina, Simon, and Lana) for their love, support, and understanding, especially when I lose the balance between work and family time.

I hope the readers will find this case atlas format to be an efficient method for learning how to manage pediatric orthopedic injuries using the current state-of-the-art techniques.

Steven L. Frick

I would like to thank Dr. Iobst for working on this text with me and for his friendship, intellect, and drive to complete academic projects that help us take better care of patients. Our few years working together showed me he is an amazing surgeon and person. I would also like to thank my colleagues at Carolinas Medical Center, Nemours Pediatric Orthopaedics, and Stanford University for improving my knowledge of pediatric musculoskeletal trauma. I hope readers will find this text practical and useful when caring for injured children and adolescents.

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Part I

Upper Extremity: Shoulder and Elbow

Medial Clavicular Physeal Separation

Stephen E. Berling and Julie Balch Samora

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Abstract

Posterior medial clavicular physeal separations are rare injuries with potentially devastating consequences. Patients can present with dyspnea or dysphagia secondary to compression on mediastinal structures which are in close proximity to the sternoclavicular joint. These injuries can be confused with a *posterior sternoclavicular dislocation*, and generally the age of the patient determines the underlying pathophysiology. Diagnosis requires a high index of suspicion and is confirmed with a CT scan. A closed reduction can be attempted however open reduction and suture fixation is often required. This is best completed with a cardiothoracic surgeon available for

assistance. We present a case of a 13-year-old male who presented with midsternal pain and dysphagia after a football injury who did well with open reduction and fixation of his medial clavicular physeal separation.

1 Brief Clinical History

A 13-year-old male sustained an injury to his right shoulder while playing football. His right shoulder was impacted into the ground followed by other players falling on top of him. He was originally seen at an outside hospital where he was given a simple sling and told to follow-up with orthopedics. He was seen the following day in the pediatric orthopedic surgery office. He had pain about his right shoulder, difficulty turning his neck, and difficulty swallowing since the fall on the day prior. On physical examination, he appeared uncomfortable but was in no acute distress and had no dyspnea. He had swelling over his right sternoclavicular joint with associated tenderness. He was distally neurovascularly intact and had good radial pulses bilaterally. There was high suspicion for posterior medial clavicular physeal separation, and the

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patient was sent to the hospital for a stat CT scan, which confirmed the diagnosis. He was admitted for immediate surgical intervention.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2

3 Preoperative Problem List

1. Right posterior sternoclavicular fracture dislocation/medial clavicular physeal separation
2. Post-traumatic dysphagia

4 Treatment Strategy

After diagnosis of a posterior medial clavicular physeal separation or posterior sternoclavicular dislocation with symptoms (dysphagia, dysarthria, and dyspnea), urgent closed reduction or open reduction with internal fixation is recommended. CT scan is important for confirmation of diagnosis, and in this case demonstrated a posterior medial clavicle fracture dislocation. A cardiothoracic surgeon was contacted and available in the unlikely event that a vascular injury occurred during reduction. An initial attempt should be made for closed reduction. A bump behind the sternum is placed. We have the luxury of having an operative O-arm™, but simple large C-arm fluoroscopy is

adequate to obtain live imaging. The sternum is prepped widely, including part of the contralateral chest wall, in case of cardiothoracic intervention. We will usually prep the entire affected upper extremity as well, in order to mobilize the arm to assist with a closed reduction. We will first try a reduction with simple arm maneuvers. We abduct and extend the arm, working against the midline bump. If this is successful, we test stability with posterior pressure on the clavicle. If this maneuver is unsuccessful, a towel clip or point-to-point reduction clamp is applied on the clavicle, just lateral to the SC joint. We try to place the tines only around the clavicle, with care not to take too much extra tissue (such as important vessels) within the clamp, and an upward force is applied. Fluoroscopy can also be used to assess the quality of closed reduction. In our case, closed reduction attempts were unsuccessful, as O-arm™ confirmed persistent displacement. The decision was made for open reduction and fixation. A direct anterior approach was taken to the medial clavicle and sternoclavicular joint. The injury was assessed and confirmed to be a physeal separation. The reduction was completed and a fixation was maintained with braided composite suture in a figure-of-eight fashion. Capsule and periosteal closure aided in reenforcing fixation. Postoperatively, he was placed into a figure-of-eight brace. Patient was admitted for overnight observation, given preoperative dysphagia.

5 Basic Principles

Posterior medial clavicle physeal separations are rare. The most common mechanism involves a direct shoulder impaction injury. Clinicians must have a high index of suspicion of a patient with medial clavicle pain or swelling, especially with symptoms of dysphagia or dyspnea. Radiographs of the clavicle are often unreliable in diagnosis though a serendipity view may be useful. CT scan has become the gold standard for radiographic diagnosis, given the fallibility of plan radiographs (Bae 2010). After diagnosis of posterior displacement, treatment is by either closed or open means. Although there is a failure rate of 64–100% with attempted closed reduction (Waters et al. 2003; Laffosse et al. 2010; Tepolt et al. 2014; Lee et al. 2014), it should still be attempted. There does appear to be a greater chance of a successful closed reduction if the injury is a dislocation rather than a physeal injury (Waters et al. 2003; Laffosse et al. 2010; Tepolt et al. 2014; Lee et al. 2014), and if treatment occurs within 24–48 h of injury (Bae 2010). Intraoperative C- or O-arm can confirm reduction. Open reduction has demonstrated excellent clinical results, along with return to previous level of sport (Laffosse et al. 2010). Large gauge nonabsorbable suture (braided composite or polyester suture) or allograft/autograft tendon weave can be utilized for fixation from the clavicle to

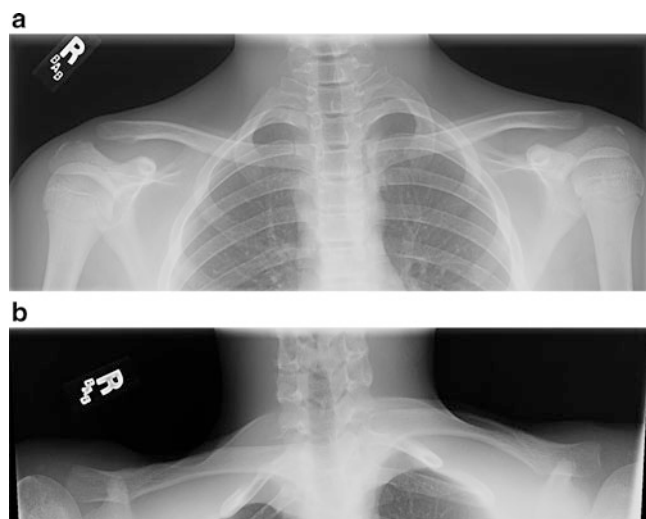


Fig. 1 Injury films including an AP of bilateral clavicles (a) which does not clearly identify injury. Serendipity view (b) which is concerning for medial clavicle injury or SC injury

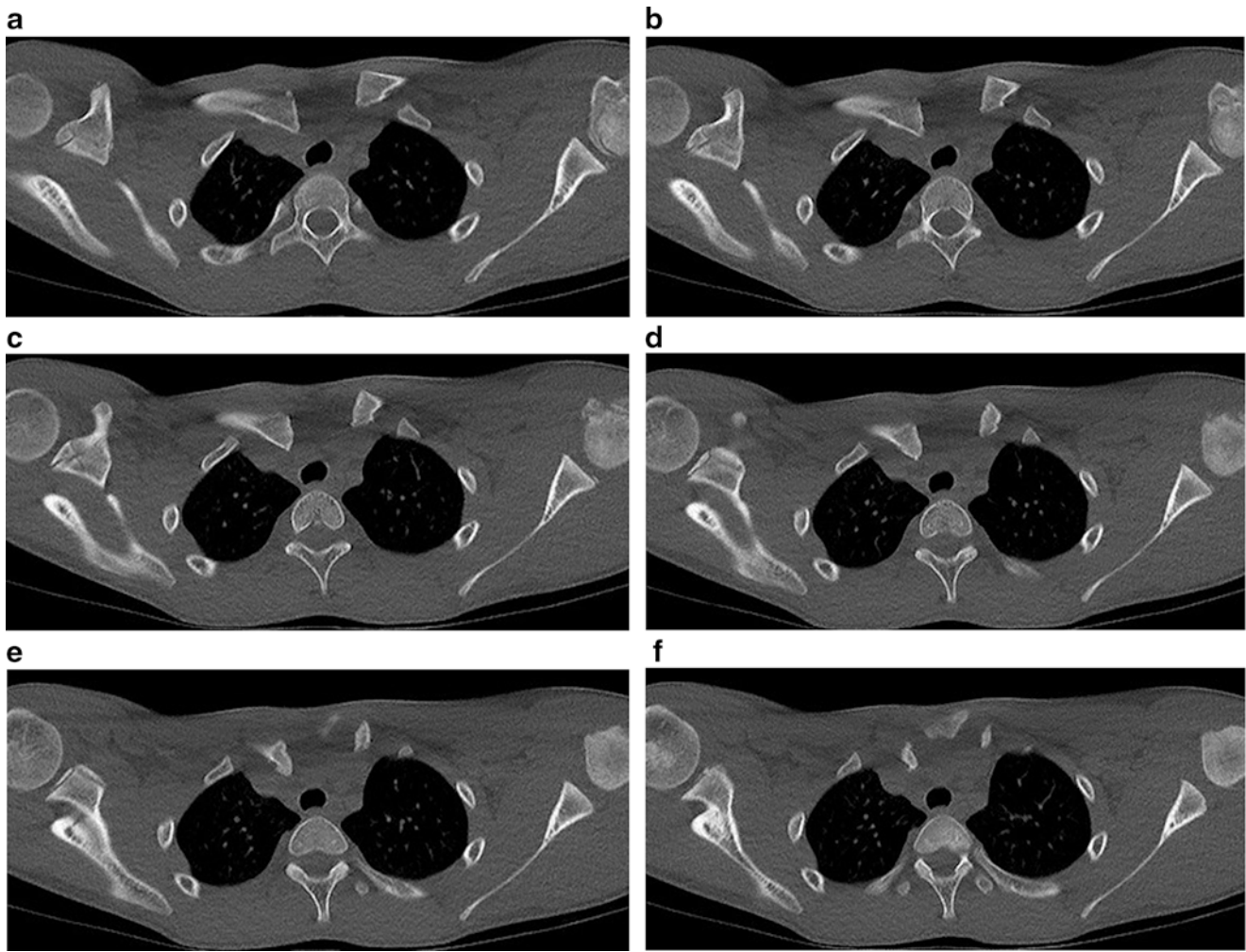


Fig. 2 Consecutive axial CT scan images (a–f) demonstrating posterior displacement of the right clavicle with associated compression on the esophagus and trachea

the epiphysis or sternum. The close proximity of mediastinal structures including the brachiocephalic veins, trachea, and esophagus necessitate careful dissection during the approach. Hohmann retractors are useful protective instruments. We generally also perform a robust capsular repair as well for further strength. It is wise to have a cardiothoracic surgeon on “back-up” during the case. Post-operative patients are kept in a sling or figure-of-eight brace for 4–6 weeks. This is typically followed by a course of physical therapy and gradual return to activities or sport in approximately 3 months.

6 Images During Treatment

See Figs. 3, 4, and 5

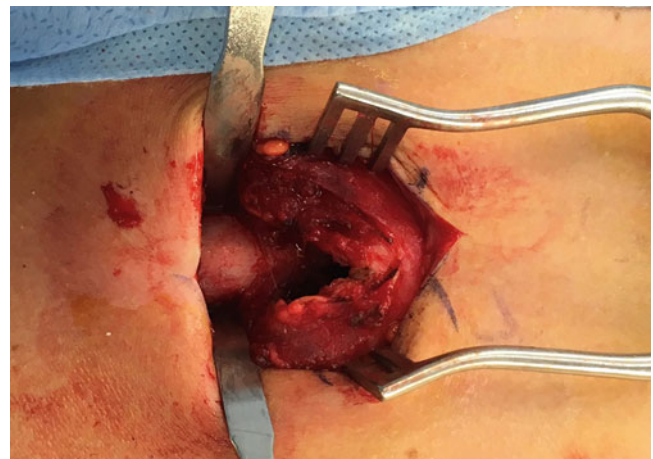


Fig. 3 Intraoperative clinical image of the exposure. Lateral clavicle (left) reduced to epiphysis (right) with opened capsule

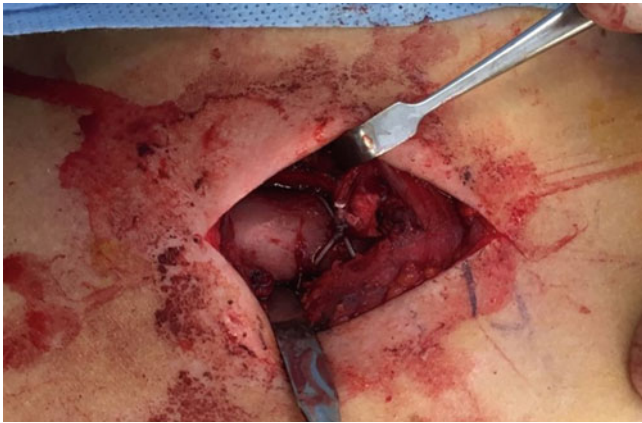


Fig. 4 Fixation of medial clavicle physeal separation with figure-of-eight suture

7 Technical Pearls

Position the patient supine with the injured shoulder near the edge of the bed. Reduction can be aided by placing a bump between the shoulder blades.

Closed reduction can be attempted with abduction and extension of the injured shoulder. Lateral traction is then applied with a posterior pressure applied to the shoulder. A percutaneous towel clip with an anterior force can be useful for attempted reduction.

Surgical approach is made through a transverse incision centered over the medial clavicle epiphysis. Attempt to preserve superficial sensory nerves. The platysma is then incised in line with the skin incision. First identify the clavicle laterally outside of the zone of injury and dissect medially towards the medial physis.

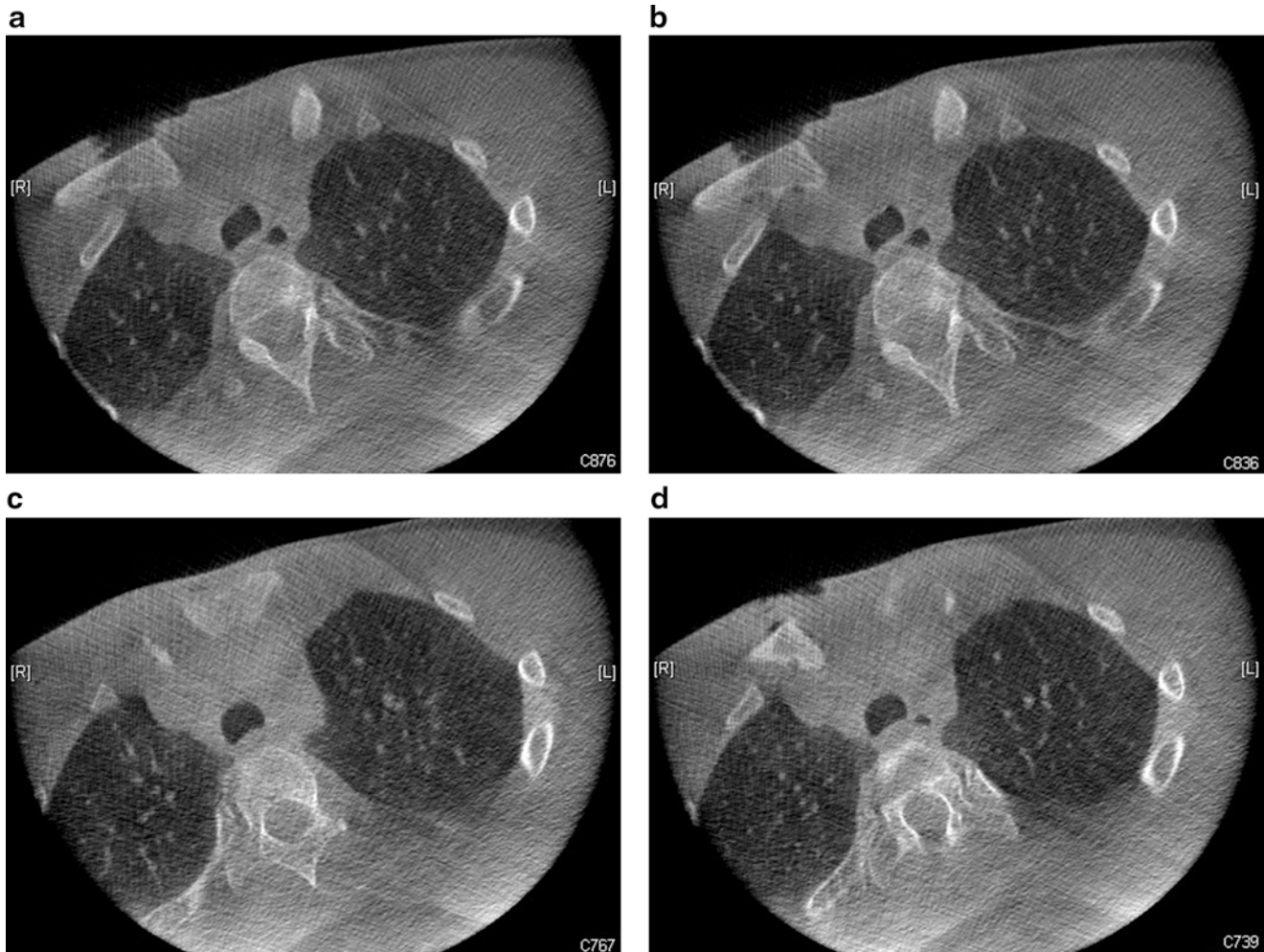


Fig. 5 Consecutive (a–d) intraoperative O-arm images with reduction of the medial clavicle physeal separation

Reduction can be completed with a towel clamp or bone clamp or even Hohmann retractors with upward pressure. This will allow lateral clavicle to clear the medial fragment.

Fixation is best completed with nonabsorbable heavy gauge suture. Options include braided composite or polyester suture (Number 1 or 2). Tendon (either allograft or autograft) fixation is another option. Two unicortical holes should be placed in the lateral clavicle and two unicortical holes placed in the medial epiphysis or sternum with a k-wire or drill bit. Care to protect the surrounding structures is critical for this portion of the case. The suture is then placed in a figure-of-eight fashion to maintain reduction.

Closure of the periosteum and capsule with absorbable sutures aids in strength of fixation in addition to making the nonabsorbable sutures less prominent. Stability should be assessed in the operative room with gentle posterior pressure on the lateral clavicle or with gentle anterior and posterior pressure, similar to the Cotton test in the ankle.

Obtaining an intraoperative C-arm or O-arm, or postoperative CT scan can be used for assessment and confirmation of the reduction.

8 Outcome Clinical Photos and Radiographs

See Fig. 6



Fig. 6 AP radiograph of right clavicle 4 weeks postoperatively

9 Avoiding and Managing Problems

A cardiothoracic surgeon should be notified and directly available during the case in case of unlikely event of vascular injury. Additionally, prepare and drape the entire chest wall in case of additional exposure needed for source control.

While exposing the injury, dissect lateral to medial along clavicle, going from known to unknown.

Avoid disrupting the posterior periosteal sleeve; this aids in maintaining resistance to posterior displacement while also protecting posterior neurovascular structures.

Avoid K-wires, pins, and screws to prevent complications with implant migration.

References and Suggested Reading

- Bae DS (2010) Traumatic sternoclavicular joint injuries. *J Pediatr Orthop* 30:63–68
- Laffosse JM, Espié A, Bonneville N, Mansat P, Tricoire JL, Bonneville P, Chiron P, Puget J (2010) Posterior dislocation of the sternoclavicular joint and epiphyseal disruption of the medial clavicle with posterior displacement in sports participants. *J Bone Joint Surg (Br)* 92(1):103–109
- Lee JT, Nasreddine AY, Black EM, Bae DS, Kocher MS (2014) Posterior sternoclavicular joint injuries in skeletally immature patients. *J Pediatr Orthop* 34(4):369–375
- Tepolt F, Carry PM, Taylor M, Hadley-Miller N (2014) Posterior sternoclavicular joint injuries in skeletally immature patients. *Orthopedics* 37(2):174–181
- Waters PM, Bae DS, Kadiyala RK (2003) Short-term outcomes after surgical treatment of traumatic posterior sternoclavicular fracture-dislocations in children and adolescents. *J Pediatr Orthop* 23(4):464–469

Lateral Clavicular Physeal Separation

Richard Reynolds

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Abstract

Lateral clavicle separations are extremely rare injuries, and recognition of the extent of the injury is the first step in having a good outcome. The mechanism of the injury in this case was a direct blow to the anterior surface of the clavicle causing failure of the lateral physis and then displacing in an arc posteriorly pivoting on the medial sternoclavicular joint to end up imbedded in the supraspinatus muscle above the scapular spine. The patient was seen by two other orthopedic surgeons who failed to recognize the severity of the injury. The patient was operated on successfully illustrating the mechanism and extent of the injury. This case illustrates the importance of recognition, mechanism, pathogenesis, and basic principles of reduction and repair.

1 Brief Clinical History

This is a 9-year-old boy who was playing football and had a direct blow from the front with a helmet. He had immediate pain swelling and disability from the injury. It was a closed injury and he had no other associated injuries. His left arm and shoulder were very painful with any motion, and the family noticed a protrusion out the back superior to the scapula. He was taken to the emergency room and it was determined he had a clavicle fracture. Two orthopedic surgeons saw the films and recommended no treatment other than observation. The family was dissatisfied with the approach and 2 weeks later came into the clinic with a markedly displaced clavicle fracture through the distal physis. There was a significant protuberance posteriorly into the supraspinatus. Neurovascular exam was normal.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

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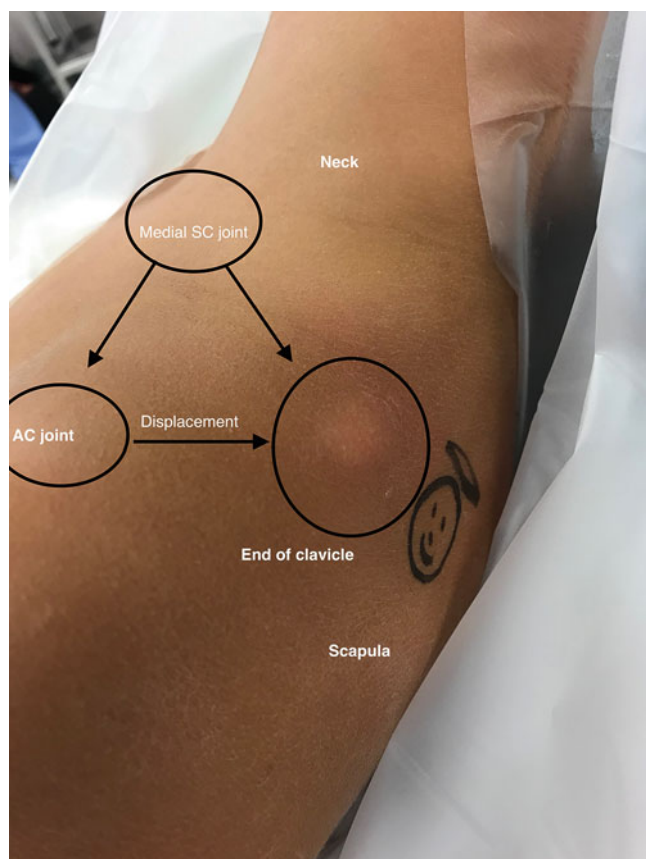


Fig. 1 This is the preoperative prominence of the distal clavicle posteriorly and above the spine of the scapula



Fig. 2 The distal clavicle is displaced with the distal AC joint intact and the distal clavicle is displaced superiorly and posteriorly

3 Preoperative Problem List

The radiographs and physical examination show a very displaced clavicle that is rotated upon the medial clavicular joint and pushing out the back of the shoulder.

1. Two-week-old injury
2. Significant displacement with prominence of the end of the clavicle
3. Shortened distance between medial clavicle and AC joint on left
4. Intact neurovascular exam (radial, median, ulnar, axillary, musculocutaneous, + radial pulse)

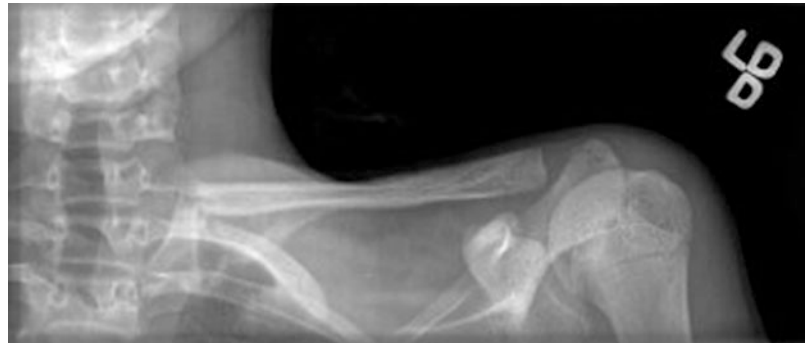
4 Treatment Strategy

Fractures of the clavicle are mostly treated nonoperatively. There is a trend to increased incidence of clavicle fractures in recent years, and more children's fractures are being treated operatively (Bae 2016). The general principles for fractures

of the clavicle remain constant with indications for operative treatment being open, tented skin, segmental, severe displacement, and neurovascular compromise. In this case the fracture is irreducible and severely displaced protruding posteriorly.

1. Patient positioned in semi-sitting position (30 degrees) bump under the shoulder.
2. U drape to isolate shoulder but to let arm move freely.
3. Anterior approach to clavicle along nearly the whole clavicle (medial clavicle to distal AC joint – not where clavicle was displaced to).
4. Incise platysma and find the clavicle medially.
5. Carry out dissection of clavicle from medial to lateral finding the rent in the periosteal sleeve and developing the plane of injury that allowed the clavicle to rotate 45° posteriorly.
6. Dissect the distal clavicular physeal separation and the intact AC joint.
7. Pull the distal clavicle out of the posterior muscle and allow the clavicle to rotate anteriorly to reduce the physeal separation.

Fig. 3 This is a more tangential view but does not show the true amount of the displacement between the ends of the fracture



8. Using no.1 fiber-wire repair the physeal separation.
9. Repair the periosteal sleeve.
10. Repair the muscle layers and platysma.
11. Subcutaneous repair with 3-0 Vicryl and 3-0 Monocryl with Prineo Dermabond mesh.
12. Post-op immobilization of the shoulder with shoulder abduction brace for 3 weeks.
13. Start pendulum exercises and active exercises at 3 weeks.

5 Basic Principles

The basic principles of this injury are to recognize what the injury is and how different it is in the pathogenesis as compared to a regular midshaft clavicle fracture. The distal clavicle fractures are so rare classification systems can be difficult to be relevant (Nenopoulos et al. 2011). The distance between the ends of the fracture is significant, in this case at least 6 cm. The periosteal sleeve is definitely torn and the fracture buttonholed through. This fracture cannot be reduced closed. The key to the reduction is to expose the plane of injury that allowed the displacement to happen. The reduction brings the clavicle back through the same plane. The fracture is distal and the AC joint is intact, and mainly cartilage sutures are the only reasonable method of fixation. Protection of the suture repair with the brace seems reasonable with early ROM.

6 Images During Treatment

See Fig. 4.

7 Technical Pearls

The positioning is key for the exposure and access to the clavicle from the front to follow the plane of displacement. The fracture was embedded in the



Fig. 4 The clavicle is reduced with sutures in place before periosteal layer closure

supraspinatus, and a lobster claw forceps was very helpful to disengage the fracture and gently pull the end of the clavicle against the intact medial sternoclavicular joint. Drill holes using a k-wire through the distal clavicle, and using the sutures to reduce the fracture displacement was very helpful. The Salter type 2 fracture distally helped line up the fracture. Meticulous repair of the periosteal sleeve is key to helping the repair strength.

The Dermabond mesh helped minimize the spread of the scar and to seal the incision in a difficult to dress region.

8 Outcome Clinical Photos and Radiographs

See Fig. 5.



Fig. 5 Intraoperative radiograph of reduction of Salter 2 of distal clavicle to AC joint. Patient refused to come back for follow-up

9 Avoiding and Managing Problems

The first step in avoiding problems with this fracture is the recognition of the injury. This is a very different type of clavicle fracture and requires a different approach. The exposure is extensile, so positioning and draping are very important, so as not to limit your incision. Finding the end of the fracture is tricky, so the technique of going from normal to abnormal anatomy is a good way to minimize soft tissue dissection. The concept of a plane of injury allows you to reverse the mechanism of injury and align the fracture while minimizing additional soft tissue injury. Anchoring the reduction is difficult due to the amount of cartilage, so screws and plates are not practical. The sutures in the cartilage do not engender confidence in the stability of the fracture, so supplemental repair of the periosteal sleeve is key to increasing the strength of the repair. The skin closure is easy, but the area is prone to the incision dehiscing and difficult to keep clean and dry, so the Prineo Dermabond mesh is a good way to help this problem.

References and Suggested Readings

- Bae DS (2016) Successful strategies for managing Monteggia injuries. *J Pediatr Orthop* 36(Suppl 1):S67–S70. <https://doi.org/10.1097/BPO.0000000000000765>
- Nenopoulos SP, Gigis IP, Chytas AA, Beslikas TA, Nenopoulos AS, Christoforidis JE (2011) Outcome of distal clavicular fracture separations and dislocations in immature skeleton. *Injury* 42(4):376–380. <https://doi.org/10.1016/j.injury.2010.09.036>

Pediatric Bony Bankart Fracture

Ryan Neeley

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Abstract

Bony Bankart lesions are avulsion fractures of the glenoid rim that occur during traumatic dislocation of the glenohumeral joint. The incidence of anterior glenoid rim fractures associated with anterior dislocation ranges from 5.4% to 44%. Initial management of a shoulder dislocation is closed reduction and immobilization. Due to risk for recurrent shoulder instability when treated conservatively, bony Bankart fractures should be treated surgically in patients who are medically stable and able to comply with postoperative protocols. When X-rays are concerning for a bony Bankart lesion, advanced imaging should be obtained after reduction to evaluate the size and quality of the bony lesion. Size of the lesion and bone quality will determine treatment type. Large fragments (>25%) may undergo open or arthroscopic reduction and fixation with cannulated screws. Smaller fragments (<25%) may undergo open or arthroscopic Bankart repair using suture anchors. Many of

these lesions are discovered in the setting of recurrent instability after a period of failed conservative treatment. With repeated episodes of instability, there is increased risk of bone loss which may affect treatment options. When >20% bone loss has occurred, a bony block procedure such as Latarjet is indicated. When surgical treatment is performed early after a single episode of instability, recurrence rates are lower than those treated after episodes of recurrent instability. Arthroscopic treatment is equally effective as open treatment in terms of recurrence.

1 Brief Clinical History

A 15-year-old male sustained an injury to his right shoulder during a football game. An opposing player hit his right arm when he was reaching up over his head. He felt like his shoulder dislocated. He was able to self-reduce at that time and did not seek medical care. Since that time he has had multiple episodes of recurrent subluxations and dislocations. He was able to self-reduce each time. He had difficulty finishing the football season due to shoulder pain and instability. X-rays and MRI were performed. His X-rays

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demonstrated a well-reduced glenohumeral joint with a large Hill-Sachs lesion and indications of a possible anterior inferior bony Bankart lesion (Fig. 1a, b, c). His MRI confirmed a bony Bankart lesion comprising approximately 25% of his glenoid surface. No signs of obvious bone loss on MRI. MRI also showed a tear of the anterior inferior labrum extending superiorly to the biceps anchor representing a SLAP tear (Figs. 1c and 2a, b, c). On physical exam with the patient supine and the arm brought to 90° of abduction and full external rotation, he had feelings of instability (apprehension test). With the arm in the same position and posterior force placed on the humeral head, he felt elimination of the feelings of instability (relocation test).

2 Preoperative Clinical Photos and Radiographs

See Figs. 1a–c and 2a–c.

3 Preoperative Problem List

1. Recurrent left shoulder dislocations
2. Left shoulder bony Bankart
3. Left shoulder anterior labrum tear
4. Left shoulder SLAP tear
5. Left shoulder instability

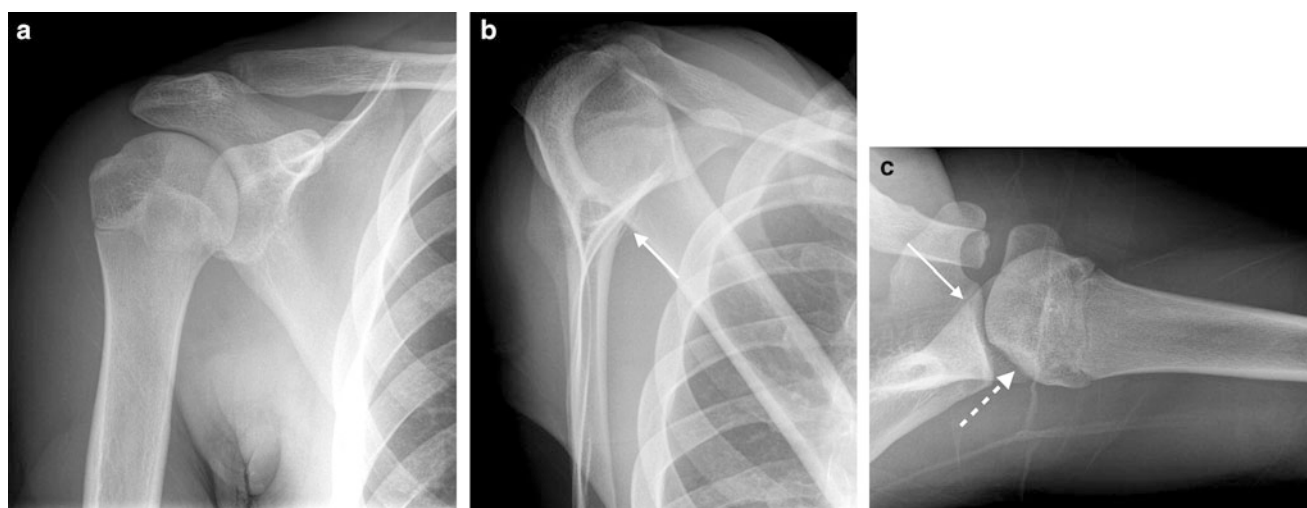


Fig. 1 AP (a), scapular Y (b), and axillary (c) X-rays are taken upon initial visit to our clinic. In (b), the arrow is pointing to a bony fleck off the anterior glenoid consistent with a bony Bankart. In (c), the solid

arrow shows the same bony fragment seen on the scapular Y view. The dashed arrow signifies the Hill-Sachs lesion

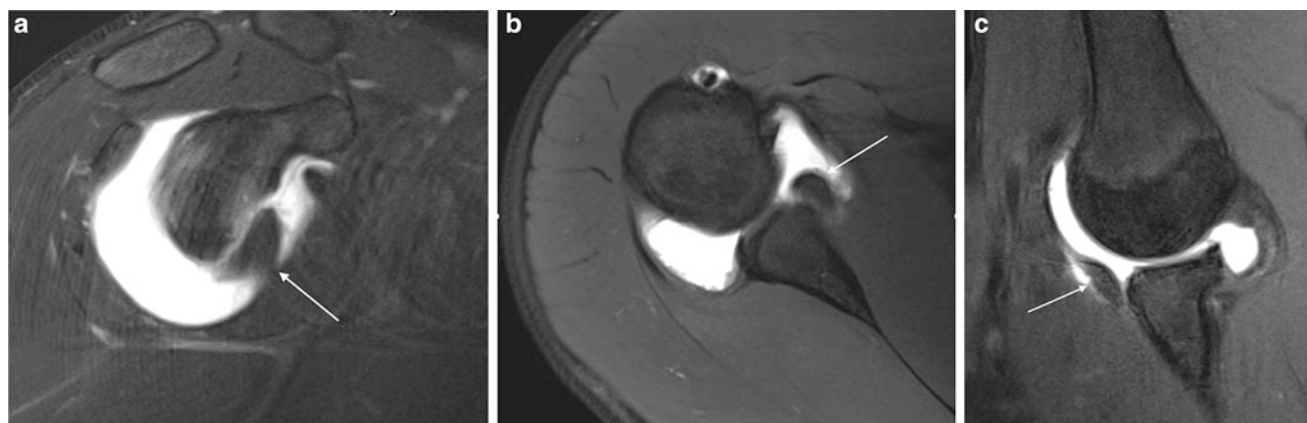


Fig. 2 MRI images of the same patient, sagittal (a), axial (b), and abduction external rotation (ABER) (c) views. These demonstrate a bony Bankart lesion measuring approximately 25% of the glenoid

surface along with a tear of the anterior labrum. The ABER view is a specialized view for accurately assessing anteroinferior labral detachment

4 Treatment Strategy

Nonoperative treatment for pediatric patients in the setting of bony Bankart does not produce good reproducible outcomes. The optimal treatment of bony Bankart fractures is dependent on size of the lesion and amount of bone loss. It is therefore imperative that adequate imaging has been obtained. Most patients should undergo MRI to evaluate the soft tissue

structures of the shoulder. A concomitant anterior labrum tear will commonly be found and must be addressed at the time of surgery. In the acute setting, most lesions are able to undergo reduction and fixation by arthroscopic or open means. Large fragments ($>25\%$) may undergo open or arthroscopic reduction and fixation with cannulated screws (see Fig. 3). Smaller fragments ($<25\%$) may undergo open or arthroscopic Bankart repair using suture anchors. In the

Fig. 3 (a, b) AP and Axillary views demonstrating an example of cannulated screw fixation of a bony Bankart fracture (Raiss et al. 2009)

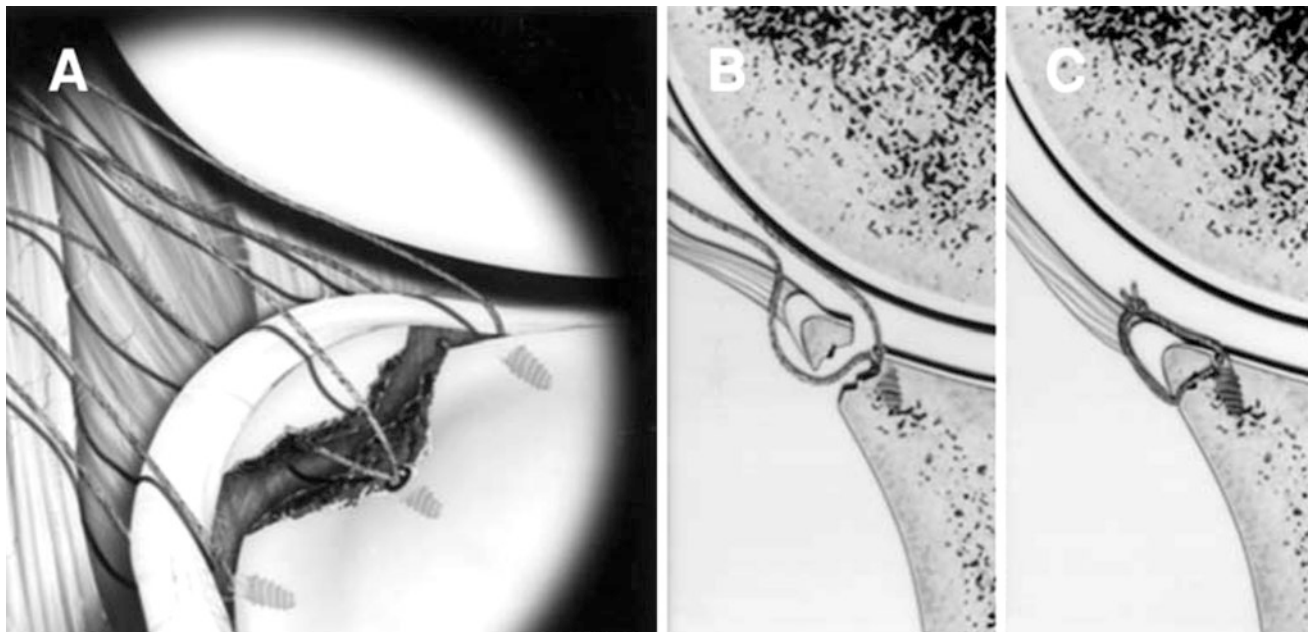
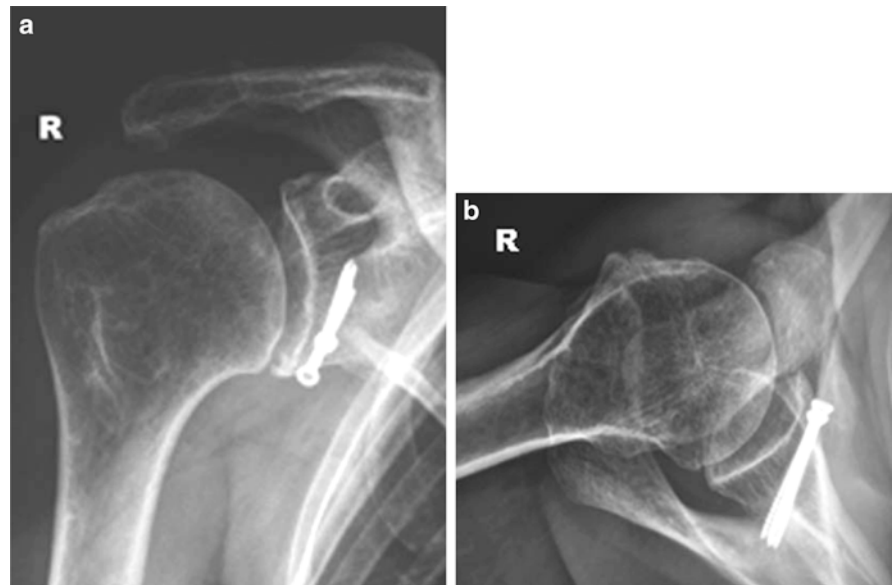


Fig. 4 Illustration of the technique used for our patient (Giuseppe et al. 2002). (b) and (c) are a close-up of the middle anchor seen in (a). This demonstrates well how the suture passes around the bony fragment and

through the entire capsulolabral complex to allow reduction of the bony fragment along with its associated soft tissue

setting of bony Bankart and recurrent instability, there is increased risk of glenoid bone loss. A CT scan is of great use in determining lesion size and amount of bone loss. 3D reconstruction of images is also helpful. If bone loss is encountered and is <20% of the glenoid surface, Bankart repair leads to acceptable outcomes with minimal recurrence. If >20% bone loss is found, a bony procedure such as Latarjet is indicated. This will not be discussed in this chapter. In our case, the patient had a bony Bankart lesion measuring 25% of the glenoid surface without signs of bone loss. He also had an anterior labrum tear extending proximally to the biceps anchor. Our preoperative plan included arthroscopic reduction and fixation of the bony Bankart lesion with suture anchor fixation along with suture anchor fixation of the labrum and SLAP tear. We also had available a 3.5 mm cannulated screw system if the bony Bankart would be amenable to screw fixation.

5 Basic Principles

1. Arthroscopic and open treatment through a deltopectoral approach are equally effective at preventing recurrent instability.
 - (A) Arthroscopic may have less pain and preservation of range of motion.
2. Perform thorough diagnostic arthroscopic exam and understand all associated pathology.
3. Anatomic reduction of bony fragment.
4. Address other associated soft tissue pathology.
5. Be aware of any glenoid bone loss before surgery

6 Images During Treatment

See Figs. 3a, b, 4a–c and 5a–c.

7 Technical Pearls for Arthroscopic Approach

1. Both beach chair and lateral position are acceptable. Beach chair offers advantage of easier transition to open approach if needed without need to reposition. Lateral position allows easier access to inferior portion of the glenoid when 6 o'clock access is required. We used a lateral position.
2. Establish a traditional posterior portal. Anteroinferior portal is established just above superior edge of subscapularis using outside in technique. A high anterosuperior portal is then established using outside in technique. After diagnostic exam, move camera to anterosuperior portal for improved visualization of the Bankart lesion.
3. Begin mobilizing the fragment using an elevator through anteroinferior portal. Sufficient mobilization has been performed when medial fibers of the subscapularis are visualized. Next prepare the glenoid using a rasp and arthroscopic shaver to create bleeding surfaces and remove loose debris.
4. Begin fixing the lesion by starting at the most inferior portion and moving proximally. Often, a percutaneous insertion is helpful for the most inferior anchor. We began by placing a double-loaded anchor percutaneously at the 6 o'clock position. It is placed on the face of the glenoid. The purpose of this first anchor is for the capsulolabral complex to adhere closely to the glenoid. This does not capture the bony fragment.
5. Next anchor is placed more proximal and slightly more medial to reduce the bony fragment. Place perpendicular to fracture. A 45° suture lasso is passed through the capsular tissue and around the bony fragment so that our suture will be circumferential around the bony piece. A probe through the posterior portal is helpful in maintaining reduction once anchors are placed and suture is tensioned (see Fig. 4).
6. Continue placing anchors proximally until the remainder of the capsulolabral complex is repaired back to the glenoid. These anchors will be placed on the face of the

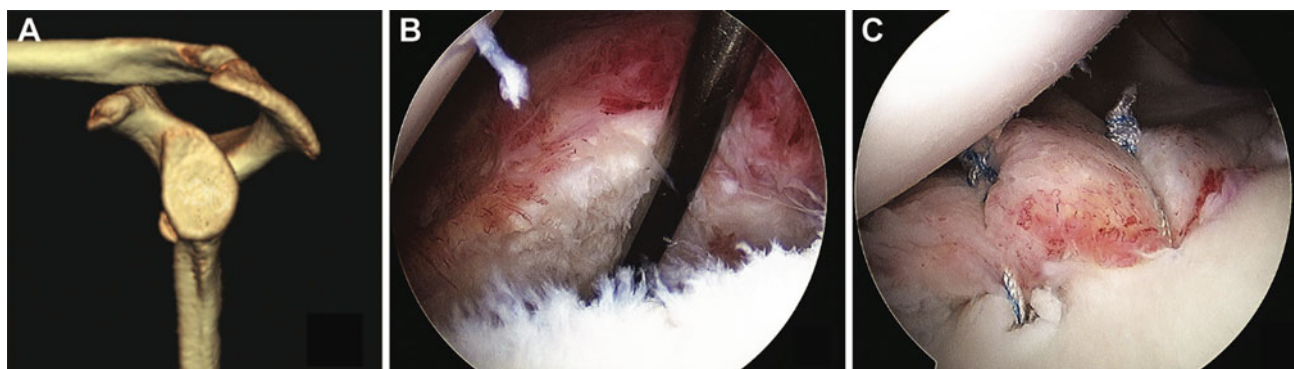


Fig. 5 (a) Preoperative CT 3D reconstruction demonstrating a bony Bankart (Kim et al. 2014). (b) and (c) are intraoperative arthroscopic images of the same shoulder viewed through a standard posterior portal demonstrating preparation and repair of a bony Bankart

glenoid surface (see Fig. 5). In our case we placed two more knotless anchors proximally to secure our Bankart repair. We did also perform a repair of his SLAP lesion which will not be discussed in this chapter.

8 Avoiding and Managing Problems

As stated previously, be sure you have adequate imaging to understand the size and quality of the bony lesion before beginning surgery. You also must understand if any glenoid bone loss has occurred and how much. When Bankart repair is performed under conditions of >20% bone loss, there is a much higher risk of recurrent instability. Treating these patients within 3 months of initial injury leads to decreased recurrence.

References and Suggested Readings

- Bigliani L, Newton P, Steinmann S, Connor P, McIlveen S (1998) Glenoid rim lesions associated with recurrent anterior dislocation of the shoulder. *Am J Sports Med* 26(1):41–45
- Gigis I, Heikenfeld R, MD, Kapinas A, Listringhaus R, Godolias G (2014) Arthroscopic versus conservative treatment of first anterior dislocation of the shoulder in adolescents. *J Pediatr Orthop* 34:421–425
- Giuseppe P, Fabrizio C, Paolo P (2002) Arthroscopic approach to acute bony Bankart lesion. *Arthroscopy: J Arthrosc Relat Surg* 18(7):764–769
- Kim Y, Cho S, Son W, Moon S (2014) Arthroscopic repair of small and medium-sized bony Bankart lesions. *Am J Sports Med* 42(1):86–94. <https://doi.org/10.1177/0363546513509062>
- Li X, Ma R, Nielsen N, Gulotta L, Dines J, Owens B (2013) Management of shoulder instability in the skeletally immature patient. *J Am Acad Orthop Surg* 21:529–537
- Raiss P, Baumann F, Akbar M, Rickert M, Loew M (2009) Open screw fixation of large anterior glenoid rim fractures: mid- and long-term results in 29 patients. *Knee Surg Sports Traumatol Arthrosc* 17:195–203. <https://doi.org/10.1007/s00167-008-0677-9>

Adolescent Clavicle Fractures

Joseph A. Janicki

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Abstract

The management of clavicle fractures in adolescence is controversial. Due to recent adult literature noting some improved outcomes in operatively managed clavicle fractures, there has been an increased interest in using operative fixation to treat adolescents. We present an athletic adolescent girl who was presented with the advantages and disadvantages of operative and non-operative management of her clavicle fracture. She ultimately decided upon operative treatment with good results and return to activity.

denies numbness of her right upper extremity. She has a history of asthma which is well controlled. She is currently the captain of the cheer squad at an elite area high school and models fashion part time.

1 Brief Clinical History

A 16-year-old adolescent female presented 2 days after a fall while wrestling with a friend with a right clavicle fracture with deformity. She complains of right clavicle pain but

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

Displaced, comminuted clavicle fracture.
Relative shortening of the clavicle
Desire to return to sports quickly
Unacceptable cosmetic appearance due to fracture deformity, patient's thin body habitus, and part-time modeling career

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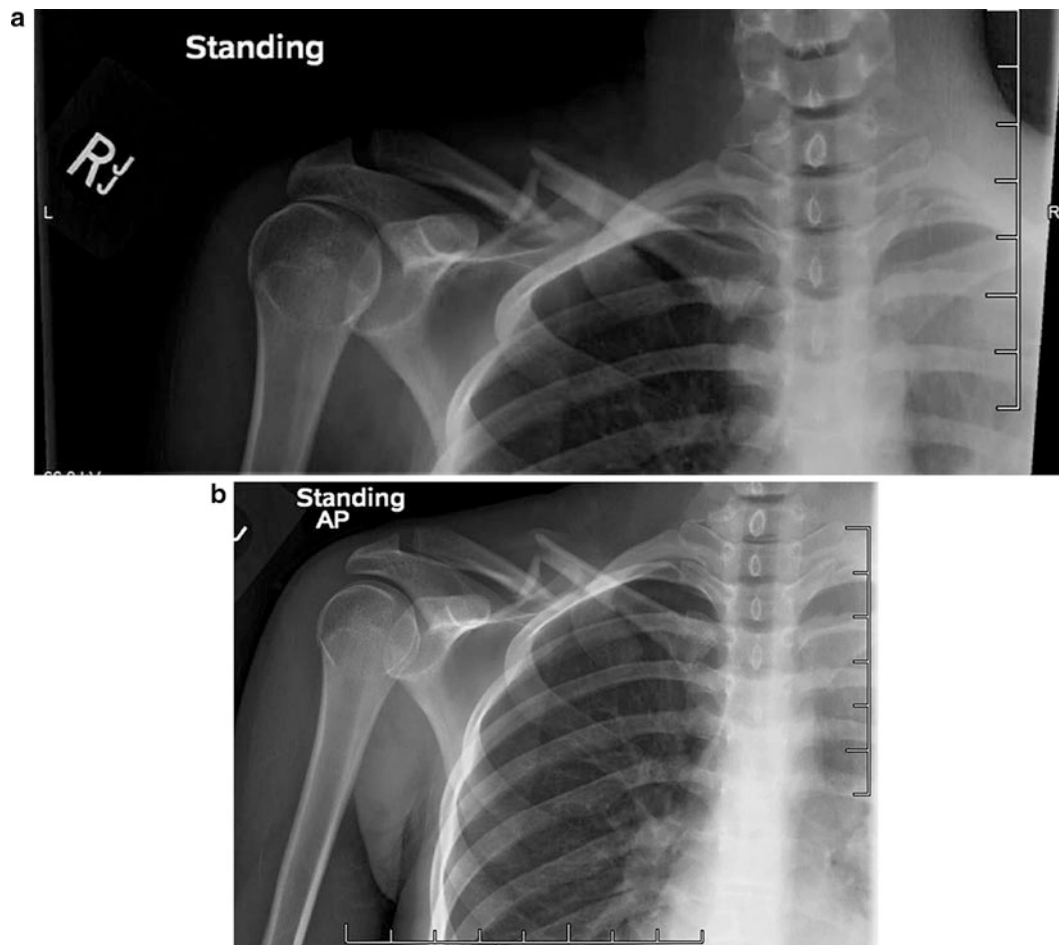


Fig. 1 (a, b) Initial injury films of comminuted right midshaft clavicle fracture. Note the relative shortening and the vertical fragment

4 Treatment Strategy

After discussion with the family including the advantages and disadvantages of operative and non-operative management, the patient and her family decided to proceed with open reduction and internal fixation of the clavicle fracture. She was taken to the operating room and underwent open reduction and internal fixation with a pre-contoured plate and screw construct.

Surgical approach: The S-shaped clavicle is approached from the anteroinferior aspect of the clavicle to prevent the scar from being directly over the clavicle. Thick subcutaneous flaps are developed. The dangers to the approach are the subclavian vein and artery and the brachial plexus. They typically pass beneath the clavicle at the junction of the medial and middle third. The subclavius protects the neurovascular structures, but care must be taken with sharp instruments in the area (ribbon retractor is a useful guard). At the medial end of the dissection, the medial branches of the suprascapular nerve are present and can cause numbness postoperatively (warn patient). Laterally the deltoid must be reflected as a flap. Do

not over strip the comminuted fragment as this may create delayed unions. Incorporating the periosteum in the layered flap can strengthen the closure to prevent dehiscence. Closure of the platysma is meticulous to prevent a deformity in the skin contour (consider nonabsorbable suture for this layer).

Careful attention was paid to the cosmetic appearance of the incision including a plastic surgery-type closure. Postoperatively she was placed in a sling for comfort. She was given range of motion exercises beginning at 1 week post-op and began therapy at 6 weeks post-op. She was allowed to return to all activity at 12 weeks post-op and is quite satisfied with her activity. While there is a scar noticeable, she is able to cover it with makeup resulting in a satisfactory appearance. Hardware has not been an issue to date.

5 Basic Principles

The traditional management of clavicle fractures in children and adolescents has been non-operative management with a sling or figure of eight splint. While generally non-operative

clavicle fracture management have good results, there are reports of pain, worse functional scores, and dissatisfaction with the appearance (Bae et al. 2013; Randsborg et al. 2014). Meanwhile, there have been prospective randomized trials in adults which found faster meantime to radiographic union, less nonunions, fewer symptomatic malunions, and improved functional scores in operatively treated clavicle fractures (Canadian Orthopaedic 2007). While similar level 1 evidence is not present in adolescents, there has been a trend toward increased use of operative management (Carry et al. 2011).

In adolescents, the absolute indications currently for the surgical management of diaphyseal clavicle fractures include open fractures, displaced fracture causing a risk of skin compromise, floating shoulder with clavicular displacement, and neurovascular injury, while strong consideration for surgical management is given to fractures with shortening if greater than 2 cm and skin tenting. It is also believed that fractures with a vertical fragment and comminution are a relative indication of surgery.

The advantages of non-operative management include avoiding anesthesia, avoiding hardware complaints and the fact that sling immobilization is generally well tolerated. The disadvantages of non-operative management include possible malalignment of the fracture with a resulting unsatisfactory cosmetic appearance, prolonged time off due to fracture healing, and a potential for fracture nonunion. The advantages of operative management include improved fracture alignment, potentially improved functional scores, lower rates of malunion and nonunion, improved comfort secondary to fracture fixation, and potentially quicker return to sports. The disadvantages of operative management include undergoing general anesthesia, a risk of infection, and hardware prominence resulting in additional surgeries for hardware removal.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

During the operative management of clavicle fractures, the surgeon should avoid placing the incision directly over the clavicle. The author prefers an incision slightly inferior to the clavicle while creating full thickness skin and tissue flaps for closure. Attempts are made to spare nerves as minor chest wall numbness is a known result of surgery. Multiple companies have pre-contoured clavicle-specific plates to aid in the operative reduction and fixation.

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

When deciding whether or not to operate, an upright x-ray is helpful to determine the real displacement and shortening. Honest discussion with family should occur including the advantages and disadvantages of operative and non-operative management including that the traditional treatment of a sling continue to have good results, while operative management may improve functional scores but at the cost of anesthesia

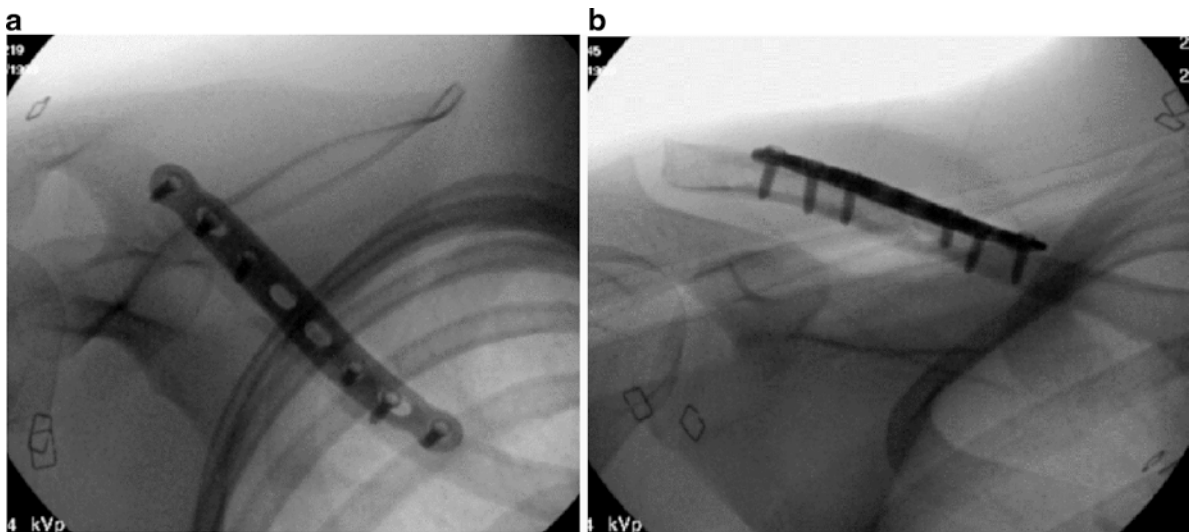
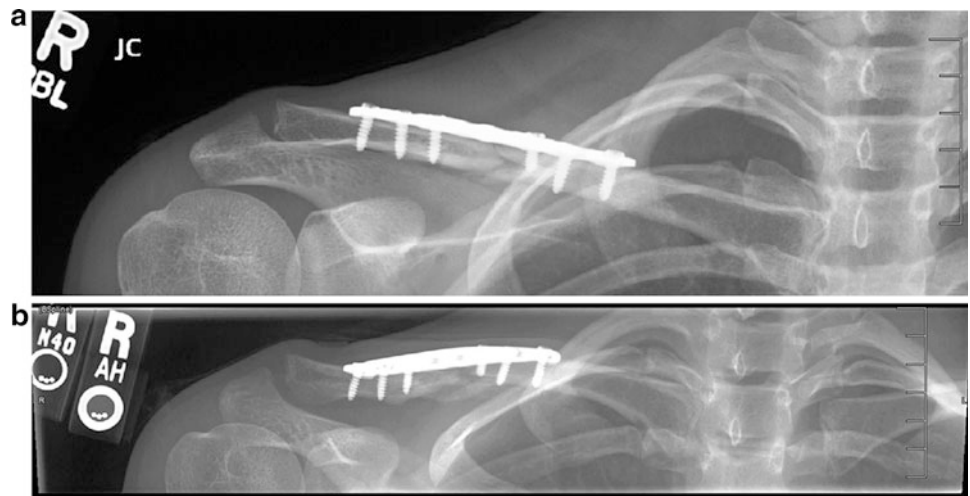


Fig. 2 (a, b) Intraoperative image of clavicle open reduction

Fig. 3 (a, b) Postoperative images of clavicle with plate fixation



risks and hardware prominence. The patient should also be warned that there may be some chest wall numbness. Patients should also be warned about returning to sports too early to avoid the possibility of refracture.

References and Suggested Readings

- Bae DS, Shah AS, Kalish LA et al (2013) Shoulder motion, strength, and functional outcomes in children with established malunion of the clavicle. *J Pediatr Orthop* 33:544–550
- Canadian Orthopaedic Trauma Society (2007) Nonoperative treatment compared with plate fixation of displaced midshaft clavicular fractures. Multicenter, randomized clinical trial. *J Bone Joint Surg* 89:1–10
- Carry PM, Koonce R, Pan Z, Polousky JD (2011) A survey of physician opinion: adolescent mid-shaft clavicle fracture treatment preference among POSNA members. *J Pediatr Orthop* 31(1):44–49
- Fanter NJ, Kenny RM, Baker CL et al (2015) Surgical treatment of clavicle fractures in the adolescent athlete. *Sport Health* 7(2): 137–141
- McIntosh AL (2016) Surgical treatment of adolescent clavicle fractures: results and complications. *J Pediatr Orthop* 36(4):S41–S43
- Randsborg PH, Fuglesang HF, Rotterud JH et al (2014) Long-term patient-reported outcomes after fractures of the clavicle in patients aged 10 to 18 years. *J Pediatr Orthop* 34:393–399

Displaced Proximal Humerus Fracture in 15-Year-Old

Emily Dodwell and Richard Reynolds

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Abstract

Pediatric proximal humerus fractures account for less than 5% of pediatric fractures. Children <5 most frequently sustain Salter Harris I fractures, 5–11-year-olds most often sustain metaphyseal fractures, and children >11 typically sustain Salter Harris II fractures. The injury is usually from a fall onto the outstretched arm, but indirect trauma may be responsible, as in the chronic Salter Harris I fracture, Little Leaguer's shoulder. Typically the proximal fragment is abducted and externally rotated, related to the pull of the rotator cuff muscles. The distal fragment (shaft)

is typically anteriorly translated, adducted, and shortened due to pull of the pectoralis and deltoid muscles. The proximal humeral growth plate closes at 14–17 in girls and 16–18 in boys. The proximal humerus is responsible for 80% of humeral growth, thus there is extensive remodeling potential in children with 1–2 years or more of growth remaining. Even without complete remodeling, due to the relatively unconstrained motion at the shoulder, significant deformity can be tolerated. Proximal humerus fractures may be classified by the Neer-Horowitz Classification or the AO Pediatric Comprehensive Classification of Long Bone Fractures system.

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1 Brief Clinical History

This 15-year-old boy was running when he tripped and fell onto his outstretched arm. He had immediate pain and disuse of the arm, without numbness or weakness. He presented to the Emergency Department where initial X-rays were

obtained (Figs. 1, 2, and 3). Physical exam showed a moderately swollen shoulder, limited in motion due to pain. Motor and sensory nerve functions were intact. There was no tenderness other than at the proximal humerus. The limb was well perfused and there was a strong radial pulse.



Fig. 1 AP radiograph of the shoulder showing approximately 50% translation, less shortening, no apparent



Fig. 2 Scapular radiograph of the shoulder showing approximately 100% translation, minimal shortening, no apparent angulation

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

- 100% translation and 80 degrees angulation of Salter Harris II fracture in adolescent with minimal growth remaining

4 Treatment Strategy

Due to the degree of displacement and angulation, and presumed minimal growth remaining in a 15-year-old nearing skeletal maturity, alignment was deemed unacceptable. A closed reduction was attempted but failed. Open reduction allowed the biceps tendon and periosteum to be removed from the fracture site. Two K-wires were inserted retrograde from a lateral starting point at the level of the deltoid insertion. The wires were started with the arm in neutral and advanced up to the fracture site. The arm was brought into abduction and external rotation, and the wires were advanced into the proximal fragment. Due to fracture instability, two additional wires were placed antegrade, starting lateral to the acromion (Figs. 4, 5, 6). He had follow-up at 2 weeks, 4 weeks for pin removal, 6 weeks, and 2.5 months, with radiographs at each follow-up visit. He regained full function of his arm and returned to sports at 2.5 months post-injury



Fig. 3 Axillary radiograph of the shoulder showing approximately 80% translation and 80 degrees angulation, Salter Harris II fracture



Fig. 4 Intraoperative fluoroscopic AP view of the shoulder showing anatomic alignment and four K-wires in situ

(Figs. 7, 8, 9). Due to his near skeletal maturity, he was deemed low risk for growth arrest, and no long-term follow-up was recommended.

5 Basic Principles

A full history should be obtained to determine mechanism of the injury and preoperative symptoms such as pain or constitutional symptoms that may suggest a pathologic fracture, and whether symptoms exist that would suggest injury to other anatomic locations, or nerve or blood vessel injury.

5.1 On Physical Exam

- Localize the area of injury
- Inspect the skin for puckering, ecchymosis, lacerations
- Assess the clavicle, ribs, sternoclavicular and AC joints, and remaining upper extremity
- Perform a complete neurovascular exam

Imaging should include AP, scapular Y lateral, and an axillary or modified axillary/Velpeau view. The axillary view is mandatory, as it rules out glenohumeral dislocation, and shows displacement and angulation that may not be



Fig. 5 Intraoperative fluoroscopic scapular Y lateral view of the shoulder showing anatomic alignment and four K-wires in situ

visualized on other views. If unable to position for a standard axillary view, a modified axillary/Velpeau view can be obtained (Geusens et al. 2006). One must determine if the fracture appears acute, chronic (Little Leaguer's shoulder), or pathologic. Ultrasound may be useful to evaluate for fracture in infants. CT scan and MRI are rarely indicated, but could be considered on a case by case basis, particularly if there is difficulty in obtaining adequate X-rays or in the case of pathologic fracture.

Proximal humerus fractures in children with >2 years of growth remaining can almost always be treated nonoperatively. For children <10, complete translation and almost any degree of angulation is acceptable. For children 10–13 complete translation and up to 60 degrees of angulation is acceptable, and for children >13, displacement of 50% of the shaft and angulation of 45 degrees is acceptable (Popkin et al. 2015; Pahlavan et al. 2011).

There are multiple options for immobilization including sling, sling and swathe, shoulder immobilizer, coaptation splint, or hanging cast. Closed reduction could be attempted, but is not required if the alignment is within the acceptable range, and may not be successful if the fracture is unstable. If proceeding with a closed reduction,

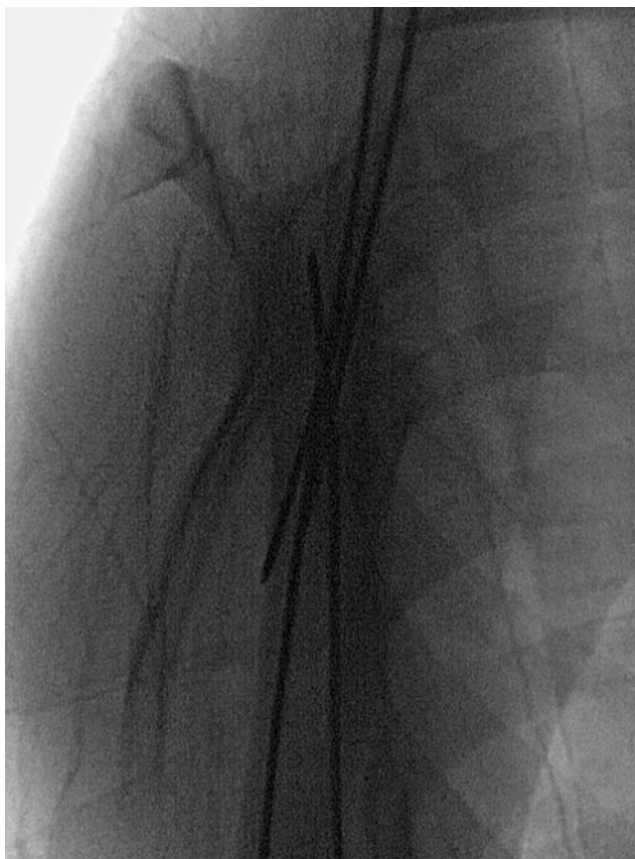


Fig. 6 Intraoperative fluoroscopic oblique view of the shoulder showing anatomic alignment and four K-wires in situ

the family should be warned that inability to reduce the fracture and loss of reduction is a possibility. Often alignment changes over the first 7–10 days as muscle splinting relaxes, and the distal shaft fragment may drop/relax into a more acceptable position.

Indications for operative treatment include:

- Open fractures
- Fractures in unacceptable alignment
- Vascular injury
- Neurologic injury
- Buttonhole/soft tissue interposition

5.2 Operative Treatment

Position the patient in the beach chair position or supine on a Jackson table. The large fluoroscopy machine is typically used and brought in from the contralateral side.

General anesthesia is preferred with muscle paralysis as necessary to assist the reduction. Nerve blocks are not



Fig. 7 AP radiograph of the shoulder at 2.5 months post-op showing anatomic alignment and extensive callus formation

typically used due to concerns for potential injury to neurovascular structures with the use of traction, and the preference to perform a neurologic exam following the procedure.

Reduction involves traction, abduction, and external rotation of the distal fragment (the shaft) to bring it in line with the abducted and externally rotated proximal fragment. If reduction cannot be obtained closed, open reduction is performed through the deltopectoral approach. The most common block to reduction is interposition of the biceps tendon. Capsule, deltoid, and periosteum could also be interposed.

Percutaneous pinning is typical, even with open reduction. Two K-wires are inserted, ideally in a divergent manner. Third and fourth K-wires could be inserted for additional stability, depending on intraoperative findings. Crossing wires at the fracture site should be avoided. Wire diameter should be selected based on size of the child, but typically ranges from 1.6–3 mm. Wires may be inserted antegrade or retrograde from a lateral starting point. The musculocutaneous nerve should be avoided anteriorly. The axillary nerve in an adult passes 7 cm from the acromion. In children, the distance may be shorter. The deltoid insertion is a safe landmark for wire insertion. Smooth wires are preferred over threaded, as

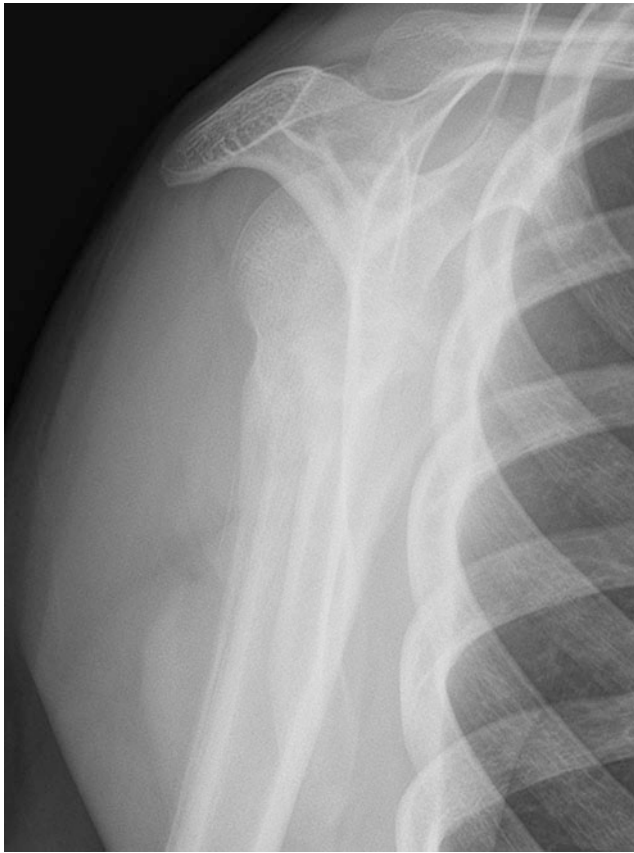


Fig. 8 Scapular Y lateral radiograph of the shoulder at 2.5 months post-op showing anatomic alignment and extensive callus formation



Fig. 9 Axillary radiograph of the shoulder at 2.5 months post-op showing anatomic alignment and extensive callus formation

they can be removed in the office, while threaded wires are more likely to require a second anesthetic for removal. The wires are bent 90 degrees and left at least 1 cm outside the skin to avoid pin migration and allow

ease of retrieval. Wires should remain in situ for 3–4 weeks. Wires remaining in situ longer than 4 weeks may be more prone to infection.

If there is a large Thurston-Holland fragment or oblique fracture, one or more small fragment cannulated or solid screws may be a reasonable option. Retrograde flexible intramedullary nails are another option. The two nails are inserted from two separate starting points along the lateral condylar ridge or directly posterior proximal to the olecranon fossa. The nails cross the physis and “skewer” the proximal humeral fragment onto the shaft (Kelly 2016; Hutchinson et al. 2011).

Whether treated surgically or nonsurgically, the fracture will take 5–6 weeks to heal, depending on the fracture pattern and child’s age. The child should be immobilized for the first 1–2 weeks, following which pendulum exercises and elbow and wrist range of motion exercises can be started. Pins may be uncomfortable in situ thus immobilization may be prolonged while pins are in situ. No overhead exercises or weights should be introduced at this time. When sufficient healing is present at 5–6 weeks, shoulder range of motion exercises can be advanced and strengthening exercises added. Typically, the child can return to sports within 2–4 months of the fracture date. Formal physical therapy is rarely required as the shoulder is very forgiving, but could be considered on a case-by-case basis. Growth plate fractures with significant growth remaining should be followed for minimum 1 year to rule out growth arrest.

6 Images During Treatment

See Figs. 4, 5, and 6.

7 Technical Pearls

- Confirm if reduction is attainable before starting pin insertion
- Avoid anterior, medial, and posterior K-wire starting points
- The retrograde starting point should be in the region of the deltoid insertion
- Start the pins with the arm in a neutral position, advance to the fracture, then reduce with abduction and external rotation and drive the pins across
- Consider proximal, anterograde starting point
- Two K-wires will often be sufficient, additional third and fourth wires could be added for stability if warranted

8 Outcome Clinical Photos and Radiographs

See Figs. 7, 8, and 9.

9 Avoiding and Managing Problems

- Avoid maintaining K-wires for >4 weeks due to risk of infection
- Anterograde K-wires may be intra-articular, avoid multiple passes, be aware of risk of septic arthritis
- Smooth pins and unburied pins allow for easier removal in office
- Select a K-wire diameter suitable for the child's size
- The more K-wires in situ, the more sites there are for potential infection or irritation of the rotator cuff; if possible use only two K-wires, additional can be added as necessary for stability
- For meta-diaphyseal fractures, K-wires may be difficult to direct, and retrograde flexible intramedullary nails may be a preferred technique

10 Cross-References

- [Displaced Proximal Humerus Fracture in 8-Year-Old](#)

References and Suggested Reading

- Geusens E, Pans S, Verhulst D, Brys P (2006) The modified axillary view of the shoulder, a painless alternative. *Emerg Radiol* 12(5):227–230. Epub 2006 May 11
- Hutchinson PH, Bae DS, Waters PM (2011) Intramedullary nailing versus percutaneous pin fixation of pediatric proximal humerus fractures: a comparison of complications and early radiographic results. *J Pediatr Orthop* 31(6):617–622. <https://doi.org/10.1097/BPO.0b013e3182210903>
- Kelly DM (2016) Flexible intramedullary nailing of pediatric humeral fractures: indications, techniques, and tips. *J Pediatr Orthop* 36(Suppl 1):S49–S55. <https://doi.org/10.1097/BPO.0000000000000755>
- Pahlavan S, Baldwin KD, Pandya NK, Namdari S, Hosalkar H (2011) Proximal humerus fractures in the pediatric population: a systematic review. *J Child Orthop* 5(3):187–194
- Popkin CA, Levine WN, Ahmad CS (2015) Evaluation and management of pediatric proximal humerus fractures. *J Am Acad Orthop Surg* 23(2):77–86. <https://doi.org/10.5435/JAAOS-D-14-00033>

Displaced Proximal Humerus Fracture in 8-Year-Old

Emily Dodwell

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Abstract

Proximal humerus fractures account for less than 5% of pediatric fractures. Most frequently, children <5 sustain Salter-Harris 1 fractures, 5–11-year-olds sustain metaphyseal fractures, and children >11 typically sustain Salter-Harris 2 fractures. The injury is usually from falling onto an outstretched arm, but indirect trauma can also be responsible, as in the chronic SH1 fracture, Little Leaguer's shoulder. Typically the proximal fragment is abducted and externally rotated, due to the pull of the rotator cuff muscles. The distal fragment (shaft) is typically anteriorly translated, adducted and shortened due to the pull of the pectoralis and deltoid muscles. The proximal humeral growth plate closes at 14–17 in girls, and 16–18 in boys. The proximal humerus is responsible for 80% of humeral growth; thus there is extensive

remodeling potential in children with 1–2 years or more of growth remaining. Even without complete remodeling, due to the relatively unconstrained motion at the shoulder, significant deformity can be tolerated. Proximal humerus fractures may be classified using the Neer-Horowitz Classification or the AO Pediatric Comprehensive Classification of Long Bone Fractures system (Slongo et al (2007) *Suppl J Orthop Trauma* 21 (10):135–160).

1 Brief Clinical History

This 8-year-old girl was on her bicycle and was hit by a car. She was thrown and landed on the ground approximately 10 ft away. The exact mechanism is unknown. She had immediate pain and disuse of the arm, without numbness or weakness. There was no head injury or other injury. She

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Fig. 1 AP radiograph of the shoulder showing 100% translation of a meta-diaphyseal fracture

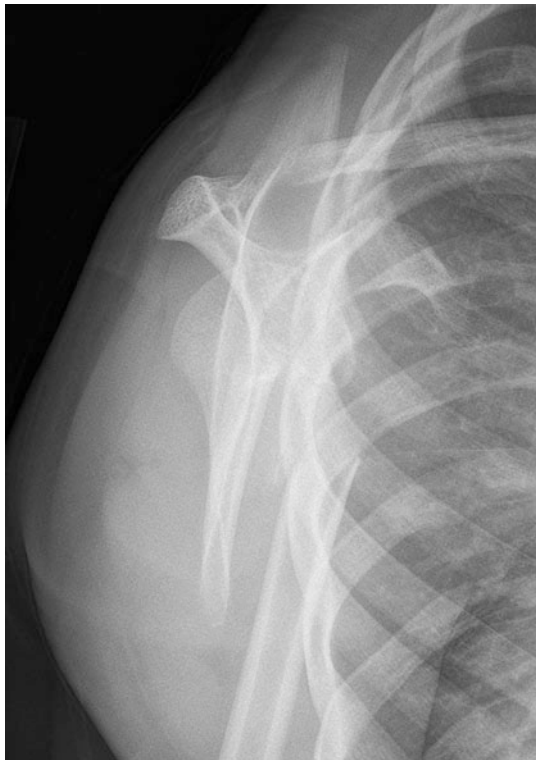


Fig. 2 Scapular Y radiograph of the shoulder showing 100% translation

presented to the emergency department where initial X-rays were obtained (Figs. 1, 2, and 3). Physical exam showed a moderately swollen shoulder, limited in motion due to pain. Motor and sensory exams were intact. There was no tenderness other than at the proximal humerus. Range of motion at the elbow and wrist was normal.



Fig. 3 Modified axillary radiograph of the shoulder showing approximately 45% angulation

The limb was well perfused, and there was a strong radial pulse.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

- High-energy trauma, rib fracture, rule-out additional injuries
- 100% translated meta-diaphyseal fracture, moderate angulation

4 Treatment Strategy

Despite the 100% translation and 45° angulation, in an 8-year-old with significant growth remaining, the current alignment was deemed acceptable. The patient was placed in a coaptation splint and had follow-up at 1 week, 2 weeks at which time the splint was discontinued, 5 weeks, and

2 months. She regained full function of her arm and returned to sports at 2.5 months post injury. As her fracture did not involve the growth plate, no long-term follow-up for this fracture was recommended.

5 Basic Principles

A full history should be obtained, to determine mechanism of the injury, preoperative symptoms such as pain or constitutional symptoms that may suggest a pathologic fracture, and whether symptoms exist that would suggest injury to other anatomic locations or nerve or blood vessel injury.

On physical exam:

- Localize the area of injury
- Inspect the skin for puckering, ecchymosis, lacerations
- Assess the clavicle, ribs, sternoclavicular and AC joints, and remaining upper extremity
- Perform a complete neurovascular exam

Imaging should include AP, scapular Y lateral, and an axillary or modified axillary/Velpeau view. The axillary view is mandatory, as it rules out glenohumeral dislocation, and shows displacement and angulation that may not be visualized on other views. If unable to position for a standard axillary view, a modified axillary/Velpeau view can be obtained (Geusens et al. 2006). It must be determined if the fracture appears acute, chronic (little leaguer's shoulder), or pathologic. Ultrasound may be useful to evaluate for fracture in infants. CT scan and MRI are rarely indicated but could be considered on a case-by-case basis, particularly if there is difficulty in obtaining adequate X-rays or in the case of pathologic fracture.

Proximal humerus fractures in children with >2 years of growth remaining can almost always be treated non-operatively. For children <10, complete translation and almost any degree of angulation is acceptable. For children 10–13, complete translation and up to 60° of angulation are acceptable, and for children >13, displacement of 50% of the shaft and angulation of 45° are acceptable (Popkin et al. 2015; Pahlavan et al. 2011).

There are multiple options for immobilization including sling, sling and swathe, shoulder immobilizer, coaptation splint, or hanging cast. Closed reduction could be attempted but is not required if the alignment is within the acceptable range and may not be successful if the fracture is unstable. If proceeding with a closed reduction, the family should be warned that inability to reduce the fracture, and loss of

reduction, is a possibility. Often alignment changes over the first 7–10 days as muscle splinting relaxes, and the distal shaft fragment may drop/relax into a more acceptable position.

Indication of operative treatment include:

- Open fractures
- Fractures in unacceptable alignment
- Vascular injury
- Neurologic injury
- Buttonhole/soft tissue interposition

Whether treated surgically or nonsurgically, the fracture will take 5–6 weeks to heal, depending on the fracture pattern and child's age. The child should be immobilized for the first 1–2 weeks, following which pendulum exercises and elbow and wrist range of motion exercises can be started. No overhead exercises or weights should be introduced at this time. When sufficient healing is present at 5–6 weeks (Figs. 4, 5, and 6), shoulder range of motion exercises can be advanced, and strengthening exercises added. Typically the child can return to sports within 2–4 months of the fracture date, following further



Fig. 4 AP radiograph of the shoulder showing the fracture unchanged in position, with interval callus formation at 5 weeks post injury

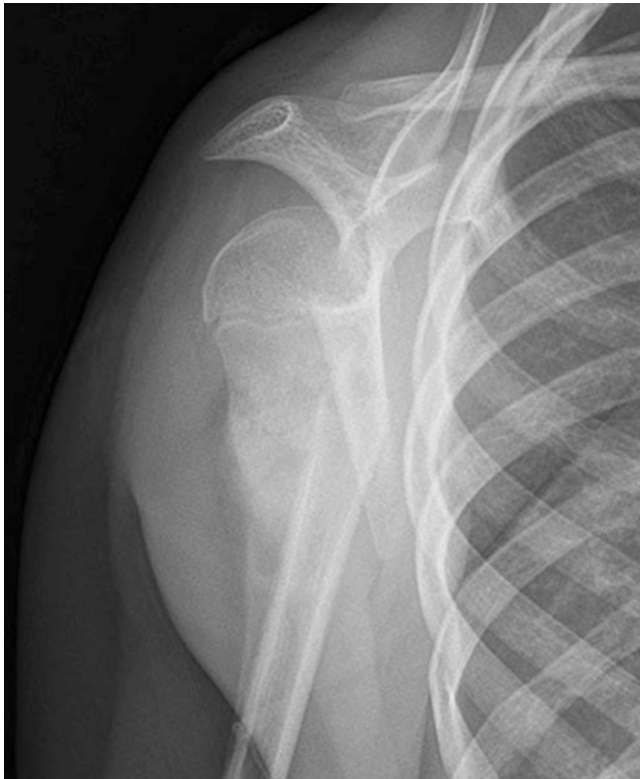


Fig. 5 Scapular Y radiograph of the shoulder showing the fracture unchanged in position, with interval callus formation at 5 weeks post injury



Fig. 6 Modified axillary radiograph of the shoulder showing the fracture unchanged in position, with interval callus formation at 5 weeks post injury

consolidation and fracture remodeling (Figs. 7, 8, and 9). Formal physical therapy is rarely required as the shoulder is very forgiving but could be considered on a case-by-case basis. Growth plate fractures with significant growth remaining should be following for minimum 1 year to rule out growth arrest.



Fig. 7 AP radiograph of the shoulder showing the fracture unchanged in position, already remodeling at 2 months post injury

6 Images During Treatment

See Figs. 4, 5, and 6.

7 Technical Pearls

- Confirm there is no shoulder dislocation and document maximum displacement by obtaining orthogonal views including axillary or modified axillary view.
- Perform a complete exam to rule out additional injuries.

8 Outcome Clinical Photos and Radiographs

See Figs. 7, 8, and 9.

9 Avoiding and Managing Problems

- Provide adequate analgesia (typically acetaminophen plus ibuprofen is sufficient, but a short course of narcotics could be considered).
- Counsel family that child may be more comfortable sleeping upright in a chair for the first 1–2 weeks.

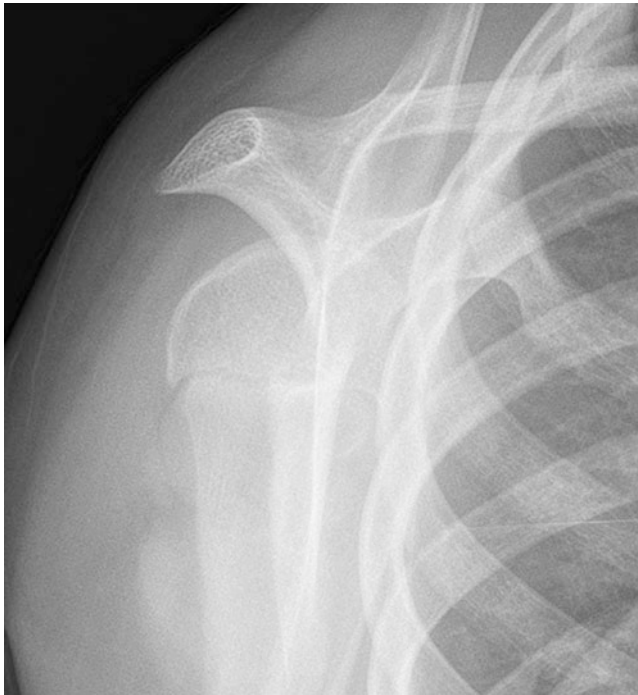


Fig. 8 Scapular Y radiograph of the shoulder showing the fracture unchanged in position, already remodeling at 2 months post injury



Fig. 9 Modified axillary radiograph of the shoulder showing the fracture unchanged in position, already remodeling at 2 months post injury

References and Suggested Readings

- Geusens E¹, Pans S, Verhulst D, Brys P. The modified axillary view of the shoulder, a painless alternative *Emerg Radiol.* 2006 (5):227–230. Epub 2006
- Pahlavan S, Baldwin KD, Pandya NK, Namdari S, Hosalkar H (2011) Proximal humerus fractures in the pediatric population: a systematic review. *J Child Orthop* 5(3):187–194
- Popkin CA, Levine WN, Ahmad CS (2015) Evaluation and management of pediatric proximal humerus fractures. *J Am Acad Orthop Surg* (2):77–86. <https://doi.org/10.5435/JAAOS-D-14-00033>
- Slongo T, Audigé L, the AO Pediatric Classification Group (2007) Fracture and dislocation compendium for children – the AO paediatric comprehensive classification of long bone fractures (PCCF). *Suppl J Orthop Trauma* 21(10):135–160

10 Cross-References

- [Displaced Proximal Humerus Fracture in 15-Year-Old](#)

Pathological Fracture of the Proximal Humerus

Nicolas Lutz

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Abstract

More than 90% of humeral bone cysts are discovered following a pathological fracture. Once diagnosed, the bony abnormality may require further imaging studies in order to specify the diagnosis and choose the appropriate treatment modality. The simple unicameral bone cyst (UBC) and aneurysmal bone cyst (ABC) are by far the most common benign lesions weakening the proximal humerus.

In young children up to puberty, UBC of the proximal humerus can be treated conservatively or surgically, depending on the size of the cyst, its location, as well as the potential for remodeling. Multiple strategies have been proposed, with or without elastic stable intramedullary nailing (ESIN), with or without intra-cystic curettage and filling.

None has proven to be better than the other. No randomized control trial has been published on the treatment of pediatric bone cysts.

Surgical treatment of UBC under general anesthesia has the advantages of allowing final histopathological diagnosis, cyst treatment such as curettage, bone substitute filling, as well as internal fixation with (Flexible Intramedullary nails), allowing permanent medullary decompression as well as early mobilization. Permanent decompression of the cyst, either with screws or intramedullary nails, appears to play an important role in the healing process. Whether ESIN accelerates the healing process of a UBC remains unclear.

The material used for cyst filling has been numerous, ranging from calcium sulfate pellets to tissue-engineered bone. The results ranged from complete healing to persistent cyst, repeated pathological fracture, and chronic pain.

Numerous studies have been published, using a noninvasive treatment for non-fractured UBC and ABC. A success rate ranging from 50 to 90% has been described with intra-cystic injections of substances such as steroids, phenol, or antibiotics.

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In summary, the general accepted principles for the treatment of a pediatric pathological fracture of the proximal humerus secondary to an UBC are:

1. Confirm that the lesion is benign.
2. Address the possibility of cyst curettage, filling, and permanent decompression.
3. Stabilize the bone by conservative or surgical means.
4. Use ESIN basic principles for surgical fixation of the bone.
5. Follow the child until complete resolution of the cyst has occurred.

1 Brief Clinical History

A healthy boy who sustained two pathological fractures of the right proximal humerus following minor trauma at age 12.3 and 13.5. (Figs. 1, 2, 3, and 4). These two minimally displaced fractures were treated conservatively at an outside hospital. An MRI was performed soon after the first fracture, suggesting a benign unicameral bone cyst (UBC). Follow-up radiographs showed good bone healing, but no disappearance

of the cyst. Observation with serial radiographs was proposed to the family and child.

At age 15.3, following a minor trauma at the gym, the child presented to our clinic with a slightly displaced third pathological fracture (Figs. 5 and 6) of the right proximal humerus. He had no neurological impairment. Once consented, aspiration and curettage of the cyst under fluoroscopy guidance followed by ESIN were performed. Two slightly prebended titanium nails size 3 were used (Figs 7, 8, 9, 10, 11, 12, 13, 14, 15, and 16).

Histopathological analysis did not show any sign of malignancy, confirming the benign nature of the cyst.

A sling was used for 10 days. Early postoperative active motion of the right arm was allowed.

Radiographs were performed at day 10 and day 45.

Plan: Nail removal when the cyst has healed, usually within 2 years of ESIN.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, 5, and 6.



Fig. 1 12.3 years old boy with first pathological fracture. Radiographs, AP view



Fig. 2 12.3 years old boy with first pathological fracture. Radiographs, lateral view



Fig. 3 13.5 years old boy with second pathological fracture. Radiographs, AP, and lateral views



Fig. 4 13.5 years old boy with second pathological fracture. Radiographs, AP, and lateral views

Fig. 5 15.3 years old boy with third pathological fracture. Radiographs, AP view



3 Preoperative Problem List

Third pathological fracture of the proximal humerus within 2 years

Large growing cyst 10×4 cm, first located in the metaphysis, now in the diaphysis

Benign looking cyst (falling leaf sign), without histopathological confirmation yet

Child with less than 2 years of growth remaining: few remodeling potential

4 Treatment Strategy

Obtain cyst content to prove that it is a benign lesion.

Perform thorough curettage to remove the cyst inner layer and decrease recurrence rate (Kadhim et al. 2016).

Perform permanent decompression of the cyst by medullary canal connection with nails.

Provide bone stability in anatomical position for early postoperative motion.



Fig. 6 15.3 years old boy with third pathological fracture. Radiographs, lateral view

5 Basic Principles

For the management of proximal pathological fracture of the humerus in a child:

- Imaging studies (CT and/or MRI) and biopsy should be performed prior to any surgical management if malignancy or an aggressive benign lesion is suspected. A histiocytosis or osteosarcoma may rarely be discovered following a pathological fracture of the humerus in children. These should be promptly recognized, confirmed by a biopsy, and treated accordingly. Similarly, benign ABC can be quite aggressive and bone destructive. In such circumstances, open surgery including resection and reconstruction with a vascularized fibula or the induced membrane humerus reconstruction technique may be necessary.
- Some pathological fractures secondary to benign cyst lesions can be treated conservatively with the arm resting in a sling for 3 to 4 weeks. Spontaneous post-traumatic disappearance of such cysts is a possibility.
- Intra-cystic injection of phenol or steroids is feasible only if the cavity is intact.
- Cyst decompression by permanent contact with the healthy medullary canal is an advantage of ESIN and considered as a major aspect of the success of such a treatment modality (Guida et al. 2016; Li et al. 2016).
- Consider filling the cavity of the cyst with whatever product you are used to (Erol et al. 2017; Traub et al. 2016).
- Basic orthopedic rules of fracture management with regard to angulation and rotation should be applied to all

Fig. 7 Patient and fluoroscopy placement in operating room



children: avoid rotational malalignment and tolerate up to 30° of axial deviation if the child has 2 years of growth remaining.

6 Images During Treatment

See Figs. 7, 8, 9, 10, 11, 12, 13, 14, and 15.



Fig. 8 Needle biopsy and aspiration of intra-cystic fluid, operative view



Fig. 9 C-arm image of needle biopsy and aspiration

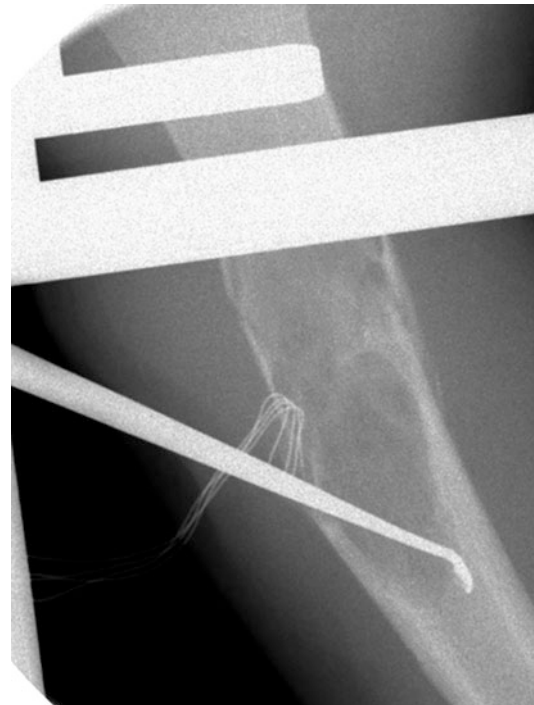


Fig. 10 C-arm image of cyst curettage and medullary canal opening



Fig. 11 Incision site on lateroposterior aspect of distal humerus above lateral condyle



Fig. 12 Exposition of distal humerus lateral aspect anterior to triceps

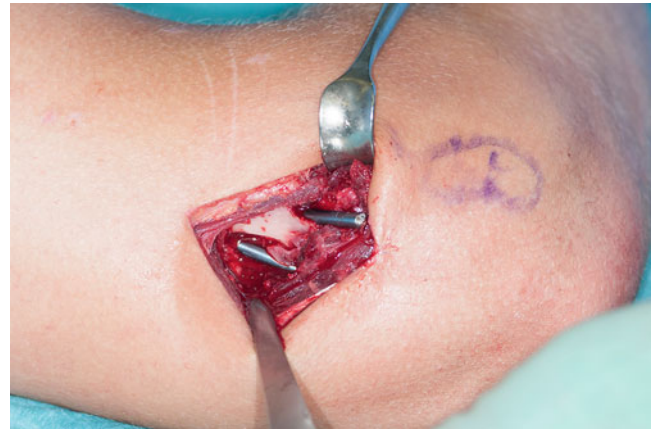


Fig. 14 Proper position and length of both nail distal ends

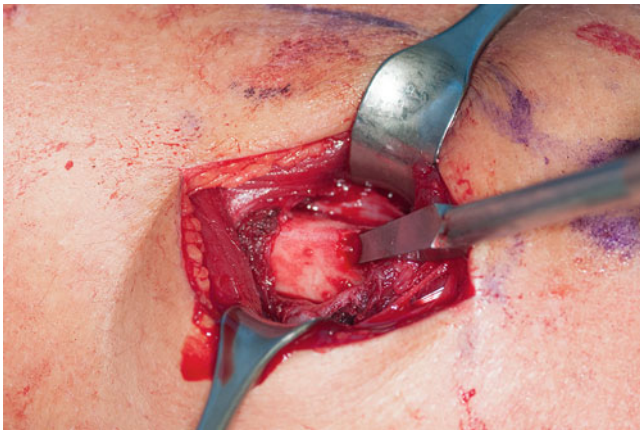


Fig. 13 Entry point of first nail performed with awl



Fig. 15 Incision closed

7 Technical Pearls

Place draped broken arm on radiolucent table for unrestricted C-arm evaluation from shoulder to elbow.

Avoid surgery more than 3–4 centimeters proximal to the lateral condyle (radial nerve).

Two separate insertion holes in the distal humerus, with the awl orientation as parallel to the diaphysis as possible, to ease insertion of the nails.

Slightly pre-bent the nails and perform multiple passages the cyst, to improve the decompression effect in the medullary canal.

If used, the bone substitute should be injected in the cyst at the end of ESIN.

Check proximal nail position by real-time visualization using the image intensifier. Avoid going through the growth plate when possible.

8 Outcome Clinical Photos and Radiographs

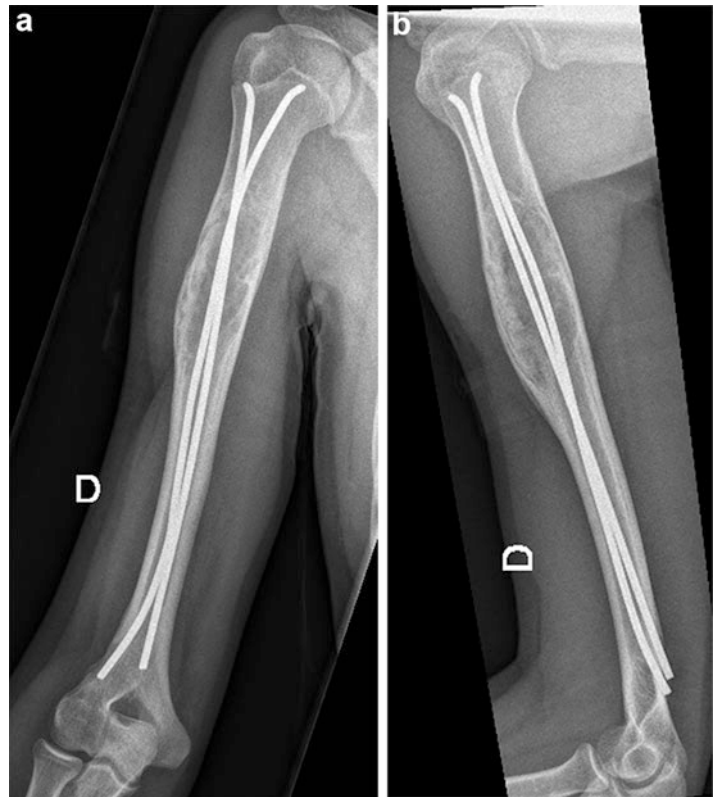
See Fig. 16.

9 Avoiding and Managing Problems

With very proximal cyst, the nails may have to be in the proximal epiphysis through the growth plate. Refrain from going through the growth plain too often while positioning the proximal tips of the nails.

Multiloculated cysts may be a challenge to perforate only with the nails. Do not hesitate to use a small direct approach and perform extensive curettage.

Fig. 16 AP (a) and lateral (b) radiographs at 4 months



Large defects in the proximal humerus requiring bone grafting may be addressed through a conventional anterior approach in the deltopectoral groove.

10 Cross-References

- [Displaced Proximal Humerus Fracture in 15-Year-Old](#)
- [Displaced Proximal Humerus Fracture in 8-Year-Old](#)
- [Pathologic Proximal Femur Fracture](#)
- [Sacral Aneurysmal Bone Cyst](#)

References and Suggested Reading

Erol B, Onay T, Topkar OM et al (2017) A comparative study for the treatment of simple bone cysts of the humerus: open curettage and

- bone grafting either without instrumentation or with intramedullary nailing. *J Pediatr Orthop B* 26(1):5–13
- Guida P, Ragozzino R, Sorrentino B et al (2016) Three-in-One minimally invasive approach to surgical treatment of pediatric pathological fractures with wide bone loss through bone cysts: ESIN, curettage and packing with injectable HA bone substitute. A retrospective series of 116 cases. *Injury* 47(6):1222–1228
- Kadhim M, Sethi S, Thacker MM (2016) Unicameral bone cysts in the humerus: treatment outcomes. *J Pediatr Orthop* 36(4):392–399
- Li W, Xu R, Du M et al (2016) Comparison of titanium elastic intramedullary nailing versus injection of bone marrow in treatment of simple bone cysts in children: a retrospective study. *BMC Musculoskelet Disord* 17(1):343
- Traub F, Eberhardt O, Fernandez FF et al (2016) Solitary bone cyst: a comparison of treatment options with special reference to their long-term outcome. *BMC Musculoskelet Disord* 17:162

Midshaft Humerus Fracture

Benjamin A. Schnee and Christopher A. Iobst

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Abstract

A 10-year-old girl presented with a left midshaft humerus fracture after falling off a bed onto her left arm. A coaptation splint was placed in the emergency room. The patient was transitioned to a fracture brace with abduction pillow 1 week after injury. She was followed weekly with radiographs in the brace until abundant healing callus and consolidation were present.

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1 Brief Clinical History

A 10-year-old girl presented to the emergency room after falling from her bed and landing on her left arm. She had no other injuries and was alert and cooperative during the physical examination. The left upper extremity was neurovascularly intact. Left humerus radiographs were obtained in the emergency department showing a transverse, midshaft humerus fracture with 36 degrees of varus angulation and 7 mm of displacement, as seen in Fig. 1a, b. A coaptation splint was applied in the emergency department under conscious sedation which provided improved alignment, Fig. 1c, d. The patient was discharged home with outpatient follow-up in 1 week.

2 Clinical Radiographs

2.1 Problem List

1. Left midshaft humerus fracture, angulated/displaced.

3 Treatment Strategy

Treatment plan was discussed with the family. The family decided for nonoperative treatment in a fracture brace. The brace was applied at 1-week post injury, as well as an abduction pillow to help correct the residual varus alignment. The brace improved alignment of the fracture, as seen in Fig. 2a, b. The fracture was then followed weekly to ensure alignment was maintained, as seen in Fig. 2c–e.

4 Basic Principles

1. The majority of midshaft humerus fractures in children are treated nonoperatively.
2. Nonoperative treatment options include fracture brace, hanging arm cast, or sling and swathe (young children).
3. A fracture brace provides hydraulic force to maintain alignment and immobilize.
4. Acceptable parameters for nonoperative management of pediatric humeral shaft fractures include 2 cm of overlap and 15–25 degrees of angulation (Caviglia et al. 2005).
5. Indications for operative intervention include open fractures, polytrauma, head injury, floating elbow, and fractures with unacceptable alignment with closed treatment.

6. Treatment course is generally weekly radiographs until adequate callus formed to ensure adequate alignment maintained, with brace removal at 6–8 weeks.

5 Images During Treatment

See (Fig. 2).

6 Technical Pearls

1. Complete physical and radiographic examinations to check for concomitant injuries or neurovascular compromise.
2. Initial immobilization in coaptation splint and placing a valgus mold will help correct the tendency to fall into varus.
3. Definitive treatment in fracture brace or hanging arm cast.
4. Begin gentle ROM at 2–3 weeks or when pain is controlled.
5. Weekly radiographs to ensure alignment maintained.
6. Abduction pillow can help correct residual varus after brace placement.

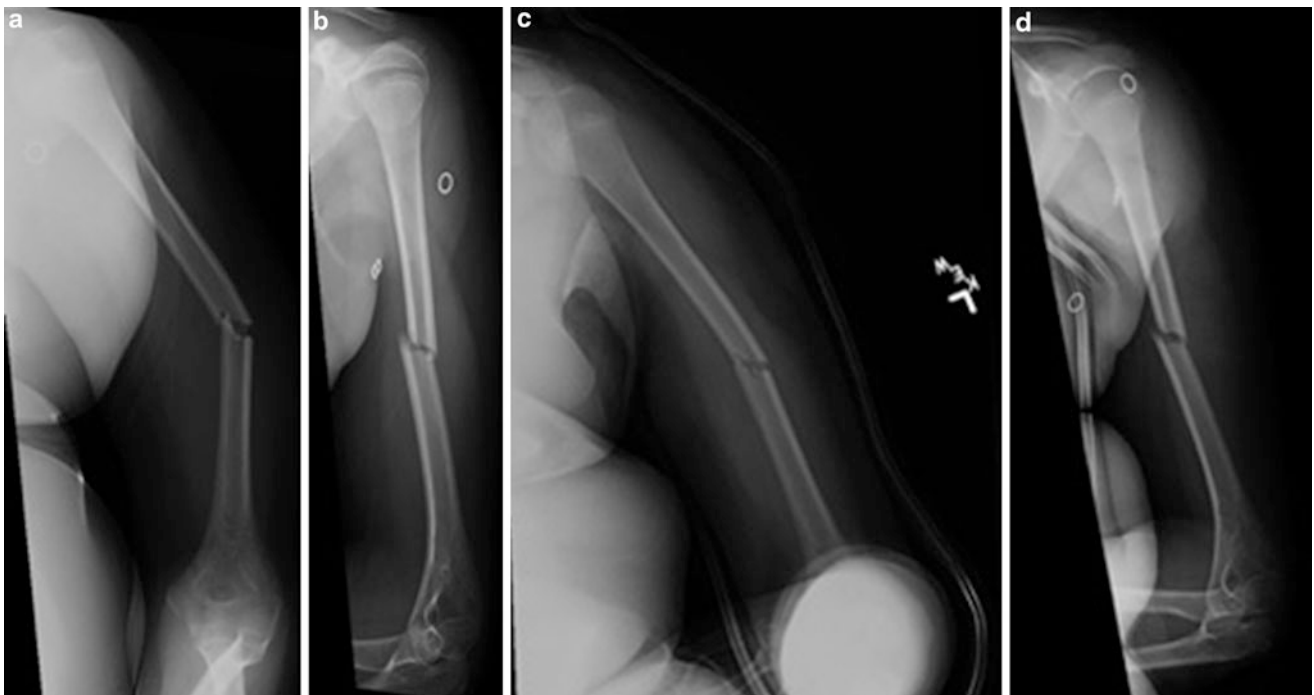


Fig. 1 Anteroposterior (a) and lateral (b) radiographs of left humerus from injury. Anteroposterior (c) and lateral (d) radiographs after coaptation splint application



Fig. 2 Anteroposterior (a) and lateral (b) radiographs at 1-week post injury with fracture brace. Anteroposterior (c) radiograph at 2 weeks and anteroposterior (d) and lateral (e) at 4 weeks showing interval healing callus formation

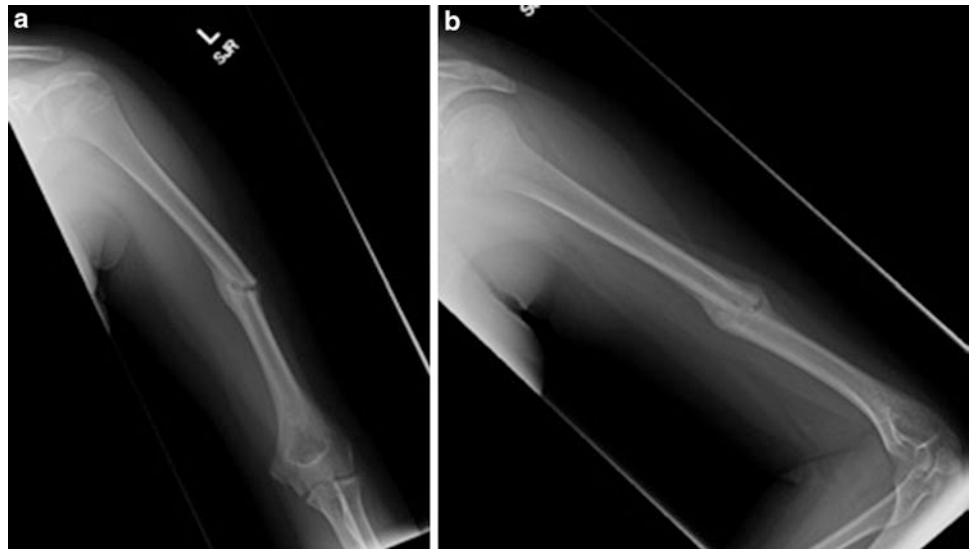
7 Outcome Clinical Radiographs

(Fig. 3).

8 Avoiding and Managing Problems

1. Discuss with the family the need to keep the brace in place and proper fit, with weekly tightening of the brace as swelling subsides.

Fig. 3 Anteroposterior (a) and lateral (b) radiograph of left humerus at 7 weeks after injury showing united fracture and will continue to remodel



2. Following the fracture weekly until radiographically stable.
3. Avoid hanging arm cast in transverse fractures patterns to avoid distraction.

9 Cross-References

- [Humeral Shaft Fracture: Flexible Intramedullary Fixation](#)
- [Humeral Shaft Fracture: Open Reduction Internal Fixation](#)

References and Suggested Reading

- Beaty JH (1992) Fractures of the proximal humerus and shaft in children. *Instr Course Lect* 41:369–372
- Caviglia H, Garrido CP, Palzzi FF, Meana NV (2005) Pediatric fractures of the humerus. *Clin Orthop Relat Res* 432:49–56
- Koch P et al (2002) The results of functional (Sarmiento) bracing of humeral shaft fractures. *J Shoulder Elb Surg* 11(2):143–150

Humeral Shaft Fracture: Flexible Intramedullary Fixation

Jennifer M. Bauer and William G. Mackenzie

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Abstract

A 13-year-old female polytrauma patient presented with multiple injuries including a right closed transverse humeral shaft fracture. In this population, this fracture is commonly managed nonoperatively. However, for stability and mobilization indications, she was treated with flexible intramedullary nail fixation through a medial and lateral retrograde technique. Multiple options exist for flexible nail entry points, but key treatment strategy includes treating length-stable fractures, obtaining 80% intramedullary fill, and keeping a widespread of the nails at the fracture site. Care should be taken to avoid and protect the neurovascular

bundles around the distal humeral entry points. She went on to robust healing and was allowed full weight-bearing at 6 weeks postoperatively.

1 Brief Clinical History

A 13-year-old female presented intubated but following commands as a level 1 trauma to our emergency department status-post scooter versus high-speed automobile. Trauma work-up revealed a right closed transverse humeral shaft fracture, along with a pneumothorax, closed head injury, skull fracture, multiple pelvic fractures, and distal femoral condyle fracture. The right upper extremity had scattered abrasions, and the distal neuromuscular exam was normal.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

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3 Preoperative Problem List

1. Polytrauma patient, intubated and sedated
2. Acute blood loss anemia requiring blood transfusion, Hgb 5.1 on arrival
3. Right widely displaced length stable transverse humeral shaft fracture



Fig. 1 Initial injury film of transverse right humeral shaft fracture

4 Treatment Strategy

Because of the polytrauma and head injuries, the decision was made to treat our patient surgically for earlier mobilization and stability. Because of skin abrasions and a stable fracture pattern, flexible intramedullary elastic nails were chosen. In this patient, her bilateral lower extremities would be non-weight-bearing because of bilateral pelvic and extremity fractures, and thus crutch weight-bearing was not a consideration.

The patient was taken to the OR 1 day after admission once hemodynamically stable and cleared. A medial and lateral dual starting point with retrograde nail passing both in the shape of a “C” was used. Alternatively, dual lateral entry may be used for mid-diaphyseal fractures such as this, bending the nails into a “C” and “S,” but this medial and lateral technique should be favored with distal diaphyseal fractures (Kelly 2016). Dissection down to bone was done to visualize the entry with a starting awl 2–3 cm proximal to the physis and avoid iatrogenic nerve injury. Alternatively, a drill can be used to open the cortex. Gently bent flexible nails were inserted from the medial and lateral distal humerus, passed across the close-reduced fracture site together, impacted short of the proximal physis, and cut to allow removal but avoid irritation. Care was taken to ensure appropriate rotational alignment.

A soft dressing and sling immobilization was applied for 2 weeks, with full weight-bearing allowed at the 6 week follow-up visit.

5 Basic Principles

1. Although the majority of humeral shaft fractures can be treated nonoperatively, indications to consider fixation include open fractures, polytrauma, head injury,

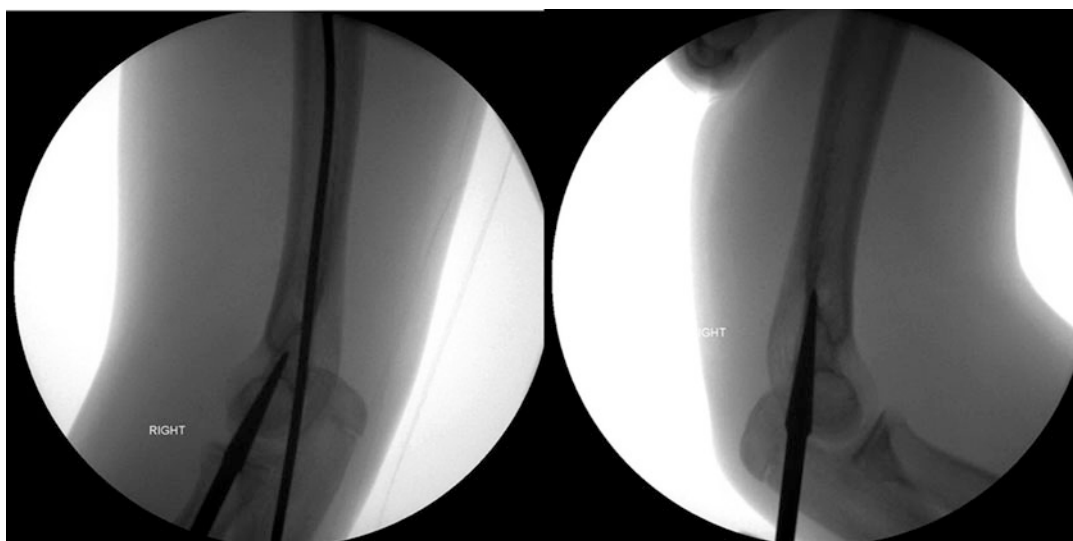


Fig. 2 Intraoperative fluoroscopy views show starting point for retrograde flexible nail placement using awl

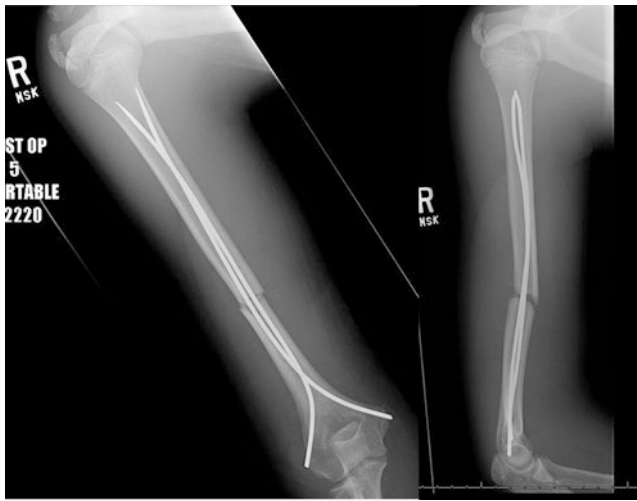


Fig. 3 AP and lateral radiograph of the right humerus fracture immediately post-op

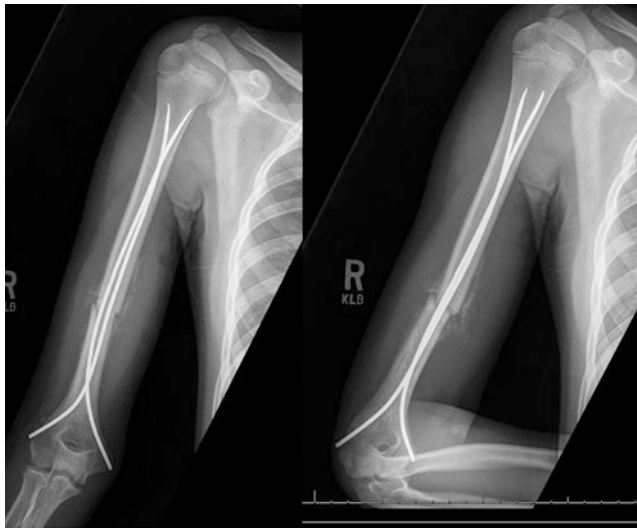


Fig. 4 Three-week postoperative radiographs show robust early callus formation and maintained fracture alignment

- floating elbow, and fractures with unacceptable closed reduction.
- Flexible intramedullary fixation is best suited to length-stable fractures but has been successful in long oblique and comminuted fractures (Lascombes et al. 2012).
 - A short course of immobilization for 1–2 weeks is commonly used for comfort and soft tissue healing, followed by encouraged elbow range of motion. Postoperative follow-up with radiographs at 2–3 weeks allows wound and alignment check, with healing and advancement to full weight bearing expected at 6 weeks.



Fig. 5 Three-month postoperative radiographs with fully bridging bone

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

- A starting awl is a safe alternative to an opening drill when in close proximity to neurovascular structures, as at the distal medial humerus.
- Nail width of 40% of the isthmic medullary canal should be chosen in the humerus for each of two implants, for a total of 80% intramedullary fill, with the widest spread between nails optimally located at the fracture site.

8 Outcome Clinical Photos and Radiographs

See Figs. 3, 4, 5, and 6.

9 Avoiding and Managing Problems

- Risk to the ulnar nerve can be avoided by dual lateral entry distal starting points, but care should still be taken for the radial nerve at the proximal extend of this approach.

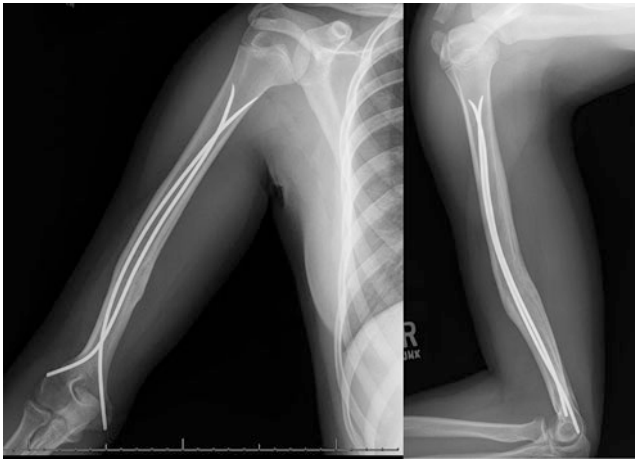


Fig. 6 Two-year postoperative radiographs show bone callus remodeling. The lateral entry flexible nail was removed at this time due to lateral soft tissue irritation. The medial entry nail was asymptomatic so was not removed

2. Malunion of $>10^\circ$ angulation has been reported in up to 25% of cases but is not associated with a worse DASH outcome score (Marengo et al. 2016).
3. The most common complications are reported to be a 15% nail migration rate in the humerus (Garg et al. 2009) and 12% soft tissue irritation and 2% osteomyelitis rate for all sites of flexible nailing (Lascombes et al. 2006). Symptomatic implants at the elbow can be removed, which is

recommended between 6 and 12 months postoperative (Kelly 2016), but there is no consensus on removing asymptomatic implants.

10 Cross-References

- Femoral Shaft Fracture: Flexible Intramedullary Nails
- Midshaft Both Bone Forearm Fracture: Intramedullary Rod Fixation
- Tibial Shaft Fracture: Flexible Nails

References and Suggested Readings

- Garg S, Dobbs MD, Schoenecker PL et al (2009) Surgical treatment of traumatic pediatric humeral diaphyseal fractures with titanium elastic nails. *J Child Orthop* 3:121–127
- Kelly DM (2016) Flexible intramedullary nailing of pediatric humeral fractures: indications, techniques, and tips. *J Pediatr Orthop* 36 (Suppl 1):S49–S55
- Lascombes P, Haumont T, Journeau P (2006) Use and abuse of flexible intramedullary nailing in children and adolescents. *J Pediatr Orthop* 26(6):827–834
- Lascombes P, Nespoli A, Poiricuitte J-M et al (2012) Early complications with flexible intramedullary nailing in childhood fracture: 100 cases managed with precurved tip and shaft nails. *Orthop Traumatol Surg Res* 98:369–375
- Marengo L, Rousset M, Paonessa M et al (2016) Displaced humeral shaft fractures in children and adolescents: results and adverse effects in patients treated by elastic stable intramedullary nailing. *Eur J Orthop Surg Traumatol* 26(5):453–459

Humeral Shaft Fracture: Open Reduction Internal Fixation

Jennifer M. Bauer and William G. Mackenzie

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Abstract

A 15-year-old boy presented as a polytrauma victim from a motor vehicle accident with a closed right comminuted humeral shaft fracture. Because of the multiple other injuries, including contralateral open distal tibia and fibula fractures, the humerus fracture was treated with open reduction and internal fixation, which allowed for earlier mobilization during a prolonged hospital stay and rehabilitation period. Key treatment strategies include using an extended deltopectoral surgical approach, choosing a stiff enough implant to allow weight bearing, and placing the plate onto the bone

with prebend and compression across the fracture. The fracture healed, and the implant was later removed when it and the surrounding robust bone mass became symptomatic.

1 Brief Clinical History

A 15-year-old boy presented intubated and sedated to our pediatric emergency department as a direct transfer, level 1 trauma alert after emergent splenectomy at an outside adult hospital from a motor vehicle accident with multiple casualties. Given his critical status, he was unable to provide a motor or sensory exam but was found to have a comminuted right humeral shaft fracture. His other known injuries at the time included an open left distal tibia and fibula fracture, nondisplaced bilateral pubic rami fractures, multiple cervical

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and lumbar compression fractures, intracranial hemorrhage, pulmonary contusion, and an open abdomen status-post emergent ex-lap.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Polytrauma patient, intubated and sedated
2. Right closed comminuted humeral shaft fracture
3. Physiologic instability, open abdomen
4. Anticipated prolonged recovery, including left lower extremity non-weight-bearing restrictions



Fig. 1 Initial injury radiograph showing right closed comminuted humeral shaft fracture

4 Treatment Strategy

Initial management of this patient's humerus fracture, as with all fractures, was to immobilize the limb for comfort and stability, which was done with a well-padded coaptation splint. Other immobilization options include sling and swath, cuff and collar, coaptation splint, functional fracture brace, or hanging arm cast. In our intubated and sedated patient who was expected to return to the OR for several operations, a coaptation splint was the best option for lying supine, frequent bed transfers, and easy access to the abdomen. While the large majority of humeral shaft fractures can be treated with one of these non-operative immobilization strategies alone, the goal in treatment in a polytraumatized patient is to promote early mobilization to decrease comorbidity. Open reduction internal fixation of this patient's humerus was planned to allow immediate arm mobilization.

Because of physiologic instability, he was not cleared for orthopedic surgical intervention until 4 days after admission at which point his abdomen was also closed. In the interim, the arm was kept splinted with daily skin checks in and around the splint.

The anterior approach through an extension of the deltopectoral interval was chosen for its relative safety and internervous plane. An attempt at anatomic reduction within the confines of the comminution was planned, with fixation using large-fragment instrumentation. Postoperatively, we allowed immediate weight bearing with a surgical incision soft dressing. Full awake neurovascular exam was normal. Postoperative exam with radiographs was done at 2 weeks and then clinical exam at 3 and 9 months.

5 Basic Principles

1. Time of fixation of fractures in polytrauma patients is dependent on physiologic stability and demands a multi-team approach and surgical clearance protocol. The fracture should be maintained in immobilization until time of surgery.
2. Acceptable alignment for non-operative management of pediatric humeral shaft fractures is up to 2 cm of override and 15–25° of angulation, with more accepted at a younger age and closer to the proximal physis (Beaty 1992, Caviglia et al. 2005).
3. The anterior approach to the humerus occurs proximally between the deltoid and pectoralis major, extending further between the bicep medially and insertion of the deltoid laterally, then dividing between the lateral and medial halves of the brachialis muscle, innervated by the musculocutaneous nerve medially and the radial nerve laterally.

Fig. 2 AP and lateral immediate postoperative radiographs show reduction with large-fragment implant. Some comminuted bone fragments can be seen within the soft tissue



6 Images During Treatment

See Fig. 2.

7 Technical Pearls

1. The deltopectoral interval can be found proximally by identifying the thin fatty streak that contains the cephalic vein. Deeper, at the level of the periosteum, the anterior humeral circumflex vasculature is encountered just lateral to the long head of the biceps tendon and must be coagulated if the fixation will extend that proximally.
2. Large-fragment implants with six cortices proximal and distal to the fracture have proven safe for crutch weight bearing in all sized adults (Tingstag et al. 2000). Here in this child, at least four cortices of fixation with good bony apposition were deemed stable for weight bearing.
3. Plate fixation on an anatomic reduced humerus is best managed with placing prebend into the plate to ensure the far cortex compresses while placing the entire plate on in compression mode. Spanning a badly comminuted section without bony apposition may be better managed with intramedullary, external, or locking fixation.



Fig. 3 Lateral 2 weeks postoperative radiograph. Some early heterotopic ossification is seen secondary to traumatic head injury

Fig. 4 AP and lateral radiograph 9 months status-post initial treatment, now 6 weeks status-post removal of symptomatic implant due to bulk of the plate and surrounding new bone



8 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

9 Avoiding and Managing Problems

1. The anterior approach to the humeral shaft, through extension of the deltopectoral interval, safely avoids the radial nerve which is encountered with a posterior approach. Staying lateral to the bicep in this interval protects the musculocutaneous nerve.
2. A neurovascular exam in humeral shaft fractures is critical with specific attention to the radial nerve function. If a palsy is present prior to treatment, no exploration is recommended and recovery is expected in 8–12 weeks. If nerve function is intact prior to treatment but there is a postoperative palsy, urgent exploration is recommended (Beaty 1992).
3. The reported rate in closed-treated adult humeral shaft fractures is 5.5%, with open reduction compression plating with grafting successfully treating over 90% (Cadet

et al. 2013). There is no published series of pediatric humeral shaft non-union, and it is thought to be exceedingly rare.

4. In the event of symptomatic robust bone formation or prominent plate, implants can be removed, as was done for this patient.

10 Cross-References

- [Femoral Shaft Fracture: Plating](#)
- [Tibial Shaft Fracture: Plating](#)

References and Suggested Reading

- Beaty JH (1992) Fractures of the proximal humerus and shaft in children. Instr Course Lect 41:369–372
- Cadet ER, Yin B, Schulz B et al (2013) Proximal humerus and humeral shaft nonunions. J Am Acad Orthop Surg 21(9):538–547
- Caviglia H, Garrido CP, Palzzi FF, Meana NV (2005) Pediatric fractures of the humerus. Clin Orthop Relat Res (432):49–56
- Tingstad EM, Wolinsky PR, Shyr Y, Johnson KD (2000) Effect of immediate weightbearing on plated fractures of the humeral shaft. J Trauma 49(2):278–280

Using External Fixation in the Treatment of Ballistic Injury to the Humeral Diaphysis in a Teenager

Michael J. Assayag and Mark Eidelman

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Abstract

A 14-year-old boy was treated with a ballistic injury to the left humerus diaphysis associated with a brachial artery injury and radial nerve palsy. Emergent operative treatment for early stabilization of the fracture, arterial reconstruction and fasciotomy was performed. Delayed definitive treatment of the fracture was done with Ilizarov-type circular external fixation. The fixator was

removed after 4 months after evidence of full consolidation on radiographs. Conservative treatment of the radial nerve palsy resulted in full recovery of nerve motor and sensitive function after 5 months. Full range of motion of the elbow from 0° to 130° was obtained at the end of treatment.

1 Brief Clinical History

This is the case of a 14-year-old boy who was brought to the emergency department after sustaining a gunshot injury to the left upper arm. Advanced trauma life support (ATLS) protocols were promptly performed. Obvious deformity of the left arm was found. Careful neurovascular examinations upon arrival demonstrated abundant bleeding from the wound,

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pulse asymmetry, and a complete inability to extend the wrist and fingers. A computed tomography angiogram (CTA) was obtained, showing a distal humeral diaphysis fracture and interruption of the blood flow in the brachial artery at the level of the injury (Fig. 1).

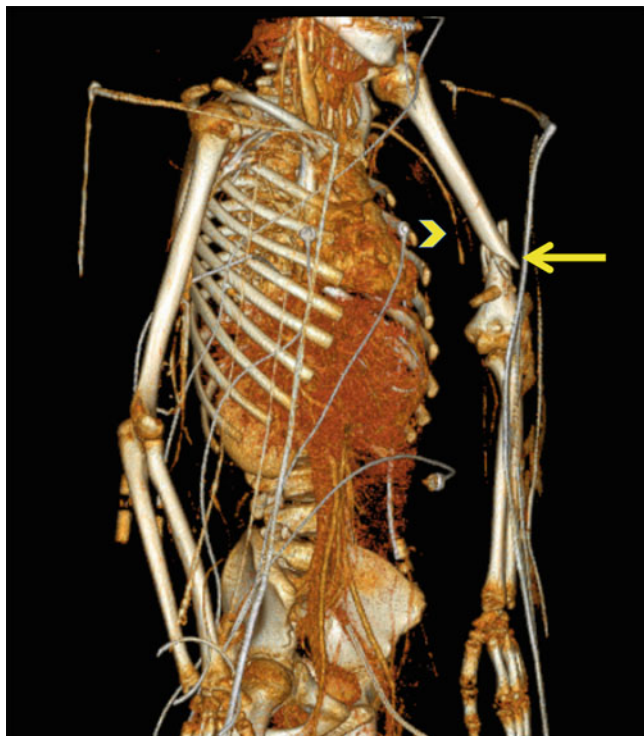


Fig. 1 Three-dimensional Computed Tomography (CT) angiogram reconstruction displaying comminuted left distal third humeral fracture (arrow) and sudden contrast interruption in the brachial artery (arrowhead)

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

- Low velocity gunshot injury to the left arm
- Open, comminuted distal-third humeral diaphysis fracture
- Acute brachial artery injury and impending limb ischemia
- Radial nerve palsy

4 Treatment Strategy

Emergent operative treatment with a vascular surgeon for hemorrhage, stabilization of the fracture using a lateral trauma external fixator, and vascular injury reconstruction using venous graft (Fig. 2). Anterior fasciotomy of the forearm was performed to decrease the risk of reperfusion injury to the limb. The radial nerve was explored and found to be in continuity. It was therefore left to recuperate. Conservative treatment of the radial nerve palsy was warranted, through physical therapy and bracing of the wrist and fingers. A few days later, when the patient was judged stable enough to undergo more extensive surgery, he was brought back electively to modify the external fixation and obtain a stable construct to allow definitive treatment of the fracture.

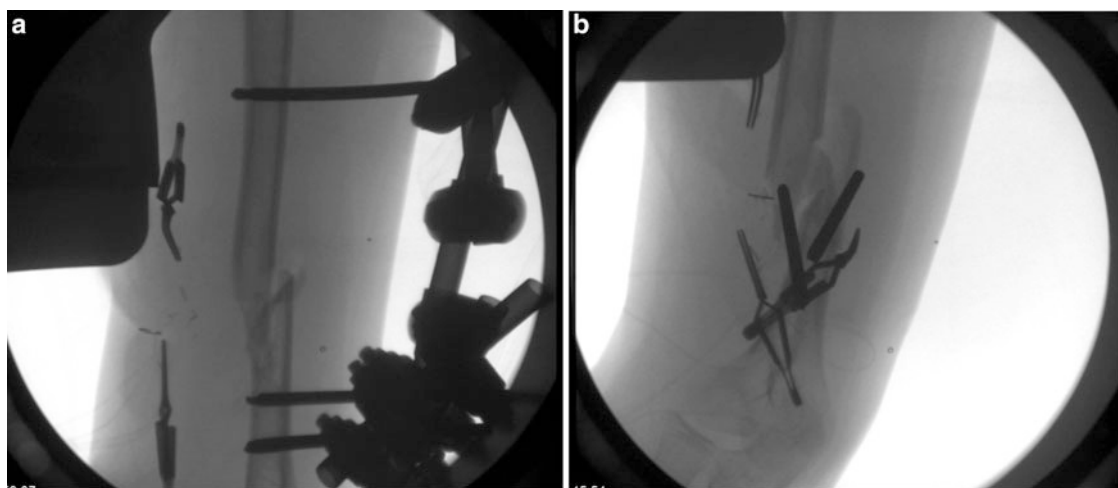


Fig. 2 (a) Anteroposterior and (b) lateral intraoperative fluoroscopy views showing hemostasis control using vascular clamps. The fracture is temporarily stabilized with a lateral trauma external fixator to allow

proper vascular reconstruction using vein graft. The fixator is positioned out of the way of the medial surgical site

5 Basic Principles

5.1 Patient Positioning

The patient is positioned as close as possible to the edge of a radiolucent table with an extension for the arm. The shoulder is abducted 45° – 60° . A roll is positioned longitudinally between the scapulae to elevate the ipsilateral shoulder. A large x-ray fluoroscopy is positioned at the head of the bed to allow biplanar intraoperative imaging.

5.2 Fixator Type

This author prefers to use an Ilizarov-type circular external fixator. It offers the option to be modified to gradually correct any residual deformity if the intraoperative reduction is imperfect. Circular fixators can be used with both static and telescopic threaded rods. Alternatively, a mono-lateral rail fixator provides enough stability for fracture healing but does not allow as much freedom for gradual angular correction during the postoperative period (Atalar et al. 2008).

5.3 Pins Placement

Half pins are usually better tolerated than tensioned wires in the humerus. Above the deltoid tuberosity, lateral to medial and anterolateral to posteromedial insertion is preferred. Care should be taken to avoid violation of the growth plate. At the tuberosity, frank lateral half pin placement is avoided to prevent injury to the radial nerve. Distal to the tuberosity, half-pins are inserted posterolateral to anteromedial as the radial nerve wraps around the humerus to follow its course between brachialis and brachioradialis muscles.

5.4 Ring Placement

Two-third rings are used distally with the opening facing anterior to facilitate elbow range of motion. Proximally, the opening is positioned medially to avoid impingement to the ribcage during activities of daily living (Fig. 3).

5.5 Building a Stable Frame

In a non-weight-bearing bone like the humerus, two points of fixation per segment is enough to provide a stable



Fig. 3 Side view (a) and posterior view (b) clinical pictures showing ring placement. The distal ring open in the front allows for elbow range of motion, while the proximal ring open medially allows for comfortable

positioning of the arm against the chest. Note the functional bracing of the wrist in extension with dynamic splinting of the fingers as a treatment for radial nerve palsy

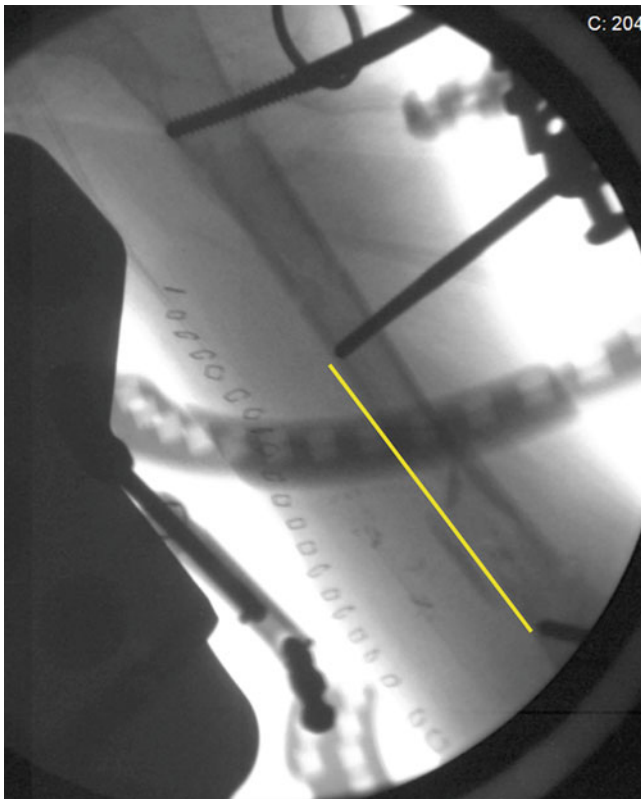


Fig. 4 Intra operative view of the fixation depicting a short working distance (yellow line)

construct amenable to bone healing. A short working distance should be obtained by positioning half-pins close to the fracture site (Fig. 4). Using the smallest rings possible, achieving 1 to 2 fingerbreadths of clearance around the soft tissues, increases stability of the construct.

6 Images During Treatment

See Figs. 3, 4 and 5.

7 Technical Pearls

Using the rings from a circular hexapod external fixation (CHEF) system offers options and versatility for multiplanar deformity correction. In-depth knowledge of the system used is important for proper hardware positioning. Practice on a saw-bone model is recommended to troubleshoot any unforeseen problem.

The surgeon can decide whether to use threaded rods, telescopic struts, or a combination (Fig. 5).

If using six telescopic struts, positioning the distal ring's first point of fixation posterolateral and the proximal ring's first point of fixation due lateral will avoid impingement in case of residual correction.

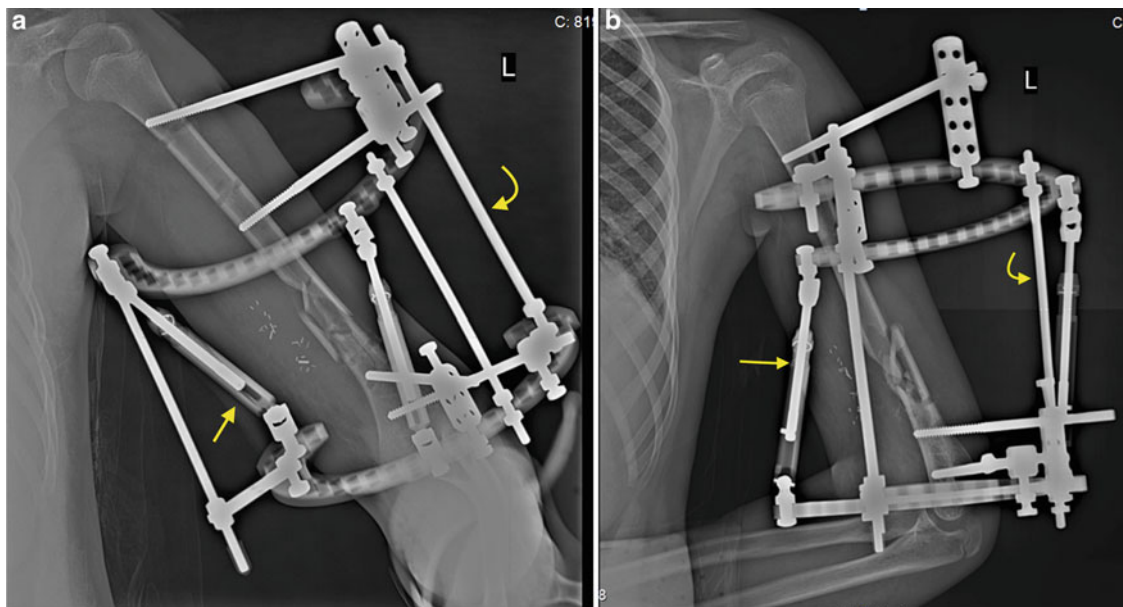


Fig. 5 Anteroposterior (a) and lateral (b) views of the humerus 1 week after definitive external fixation. These radiographs demonstrate the hybrid use of threaded rods (curves arrows) and telescopic struts (straight arrows) for ease of application and stability

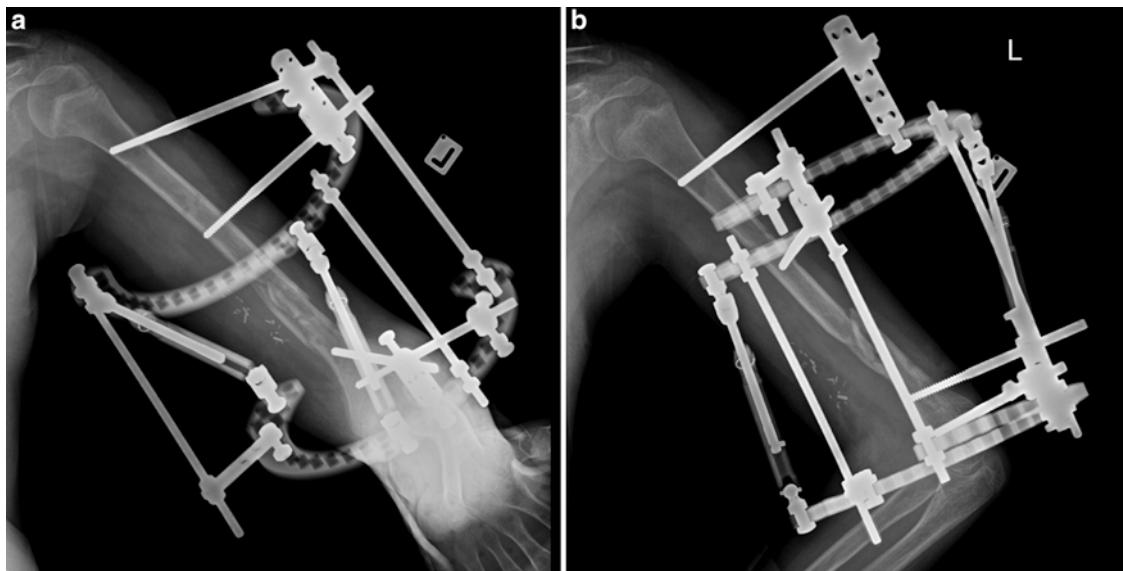


Fig. 6 Anteroposterior (a) and lateral (b) views of the humerus 2 months after the initial injury demonstrates adequate callus formation



Fig. 7 Anteroposterior (a) and lateral (b) views of the humerus 6 weeks after external fixation removal showing full consolidation of the fracture. The fixator was removed 4 months after the initial injury. The patient

regained full flexion and extension of the elbow, as well as full abduction and flexion of the shoulder

A distal reference makes it easier to obtain radiographs orthogonal to the ring in the postoperative period to assess residual deformity.

If a monolateral fixator is used, all pins are positioned laterally in a single plane. The distal pins should be as close as possible above the olecranon fossa (Scaglione et al. 2015).

8 Outcome Clinical Photos and Radiographs

See Figs. 6 and 7.

9 Avoiding and Managing Problems

Avoid intraoperative delays and problems by carefully planning all pin placements, ring sizes, and positioning on preoperative radiographs.

Use small diameter such as 4.5 mm pins, and center them in the bone for bicortical purchase to avoid fractures through pin sites. In case of fracture, the fixator needs to be extended beyond the fracture site.

Pins transfixing the bulk of the triceps should be avoided to prevent hindrance of elbow range of motion. Early mobilization of the shoulder and elbow is encouraged immediately after surgery to prevent joint contractures.

Careful knowledge of the upper extremity anatomy is necessary to avoid neurovascular injury during half-pin placement. The surgeon can refer to the *Atlas for the Insertion of Transosseous Wires and Half-pins* (Catagni 2003).

Pin sites infection should be recognized and treated promptly to avoid deep propagation.

In case of nerve palsy related to the initial injury, prompt conservative treatment with physical therapy and functional bracing (Fig. 3) will avoid loss of function.

Nerve conduction studies can help assess the potential for recovery.

In case of arterial reconstruction, careful postoperative serial vascular examinations need to be performed. Any decrease in pulses or change in Doppler flows needs to be addressed promptly with the vascular surgery consultant.

10 Cross-References

- [Distal Tibial Shaft Fracture with Metaphyseal Extension: External Fixation](#)
- [Humeral Shaft Fracture: Flexible Intramedullary Fixation](#)
- [Humeral Shaft Fracture: Open Reduction Internal Fixation](#)
- [Tibial Shaft Fracture Treated with a Circular External Fixator](#)

References and Suggested Readings

- Atalar AC, Kocaoglu M, Demirhan M, Bilsel K, Eralp L (2008) Comparison of three different treatment modalities in the management of humeral shaft nonunions (plates, unilateral, and circular external fixators). *J Orthop Trauma* 22(4):248–257
- Catagni M (2003) *Atlas for the insertion of transosseous wires and half-pins: Ilizarov method*. Medi Surgical Video, Milan
- Scaglione M, Fabbri L, Dell'Omo D, Goffi A, Guido G (2015) The role of external fixation in the treatment of humeral shaft fractures: a retrospective case study review on 85 humeral fractures. *Injury* 46(2):265–269

Type III Supracondylar Humerus Fracture

Richard Reynolds

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Abstract

Supracondylar humerus fractures are classified by Gartland I-II-III (de Gheldere and Bellan, Indian J Orthop 44 (1):89–94, 2010). The completely displaced fractures are classified as Gartland Type III. The Gartland classification system is becoming obsolete, and more modern classifications are adding a Type IV for the completely displaced fractures (Audige et al., Acta Orthop 88 (2):133–139, 2017). Type III fractures are one of the common fractures admitted for treatment in hospitals and often require prolonged hospital stay due to the risks vascular injury, neurologic injury, and open injuries. The treatment is comprised of anatomic reduction, skeletal

stabilization, and minimizing complications. In Type III fractures, the incidence of open reduction should be low and the complications of neurovascular complication rare.

1 Brief Clinical History

The patient is 7 years old and was running in the woods. He fell on his outstretched arm and sustained an injury to his left arm. There were no other injuries and the arm had significant antecubital bruising with a pucker sign. The hand was pink and perfused and there was no blood on the skin.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

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Fig. 1 Clinical photo of arm with swelling

3 Preoperative Problem List

1. Markedly displaced supracondylar humerus fracture
2. Tented skin over the fracture (pending open injury)
3. Neurovascular structures displaced but intact as of now

4 Treatment Strategy

1. Immediate treatment initiated – If this fracture occurs, should not wait overnight. The swelling and potential for neurovascular compromise is high and the skin if held in this position for long may sustain necrosis. Take patient to OR urgently within 1–2 h. Do not manipulate arm in ER without good control and ability to manage sudden loss of vascular supply.
2. Under general anesthesia, apply traction in line with the fracture alignment. Do not hyperextend the fracture. If the Brachialis is buttonholed then milking the muscle to pull the muscle over the proximal portion of the humerus then apply traction to get the ends of the bones out to length. Check position with fluoroscopy.
3. Correct medial and lateral displacement.
4. Apply pressure in the olecranon fossa and push anteriorly.



Fig. 2 Injury film in the ER lateral film

5. Flex the arm while applying traction and pushing in the olecranon fossa. The arm should flex to 120–130°. Check alignment with fluoroscopy.
6. Tape arm in hyperflexed position.
7. Place 2 mm k wire across the fracture to maximize distance between pins at level of fracture and use lateral pins divergently if fracture pattern allows it.
8. Assess distal pulse and perfusion to insure remains intact.
9. Apply splint with arm in 60° of flexion to allow for venous drainage.
10. Reassess distal pulse and perfusion of hand in operating room after fixation and immobilization.
11. Keep patient in Hospital for 24 h to monitor vascular perfusion.

5 Basic Principles

Reduction

- Longitudinal traction, correction of medial-lateral displacement, correction of rotation deformity, correc-

Fig. 3 Injury film in the ER
AP view



Fig. 4 AP view of the reduced and pinned fracture. Note the fracture is higher than the usual; therefore, the pins are closer and not as divergent as suggested



Fig. 5 Lateral view of the reduced and pinned fracture good alignment achieved and pins are in the center of the bone

tion of posterior displacement of distal fragment, and hyper extension deformity

- Tape reduced fracture in place (Hyperflexed $>120^\circ$)
- Draw line on the arm, in line with the plane of the humerus

Stabilization

- Use 2 mm K wires (stiffness of the pin is correlated to radius to 4th power)
- Use lateral pins in a divergent pin pattern whenever possible to limit risk to ulnar nerve



Fig. 6 The fluoroscopy unit should have the receiver in the superior position to decrease radiation in the room

- Maximize distance between pins at level of fracture. Have pins cross outside skin. Capture medial column and lateral column with pins

Post op

- Splint arm in relative extension to allow for venous drainage.
- Pins are in for 3 weeks.
- Start active ROM in 3 weeks postinjury.
- Nearly full ROM should be established by 8 weeks if not then start physical therapy.

- 4. Keep the receiver of the fluoroscopy in the superior position as this decreases radiation dose to all in room by 50%.

8 Outcome Clinical Photos and Radiographs

See Figs. 7, 8, 9, and 10.

6 Images During Treatment

See Figs. 4, 5, and 6.

7 Technical Pearls

1. Anatomic reduction is key to a stable fracture post-op.
2. The concept of flexing the elbow and pinning it removes one degree of motion to the fracture when you are pinning it.
3. Drawing the plane of the humerus allows for the operator to know where the bone is in the very swollen arms.

9 Avoiding and Managing Problems

Avoid the ulnar nerve when you can (Reynolds and Mirzayan 2000). The meta-analysis of ulnar nerve injuries with crossed pins ranges from 10% to 20%. This means if you do 100 cross pin stabilizations of supracondylar humerus fracture per year, then you will have 10 cases of ulnar neuropraxia per year. If the incidence of fracture patterns not amenable to lateral pinning is 10% (medial column comminution, oblique fracture patterns, or very high fractures) and you do cross pins for only 10/100, then you will only have 1 case per year.

Do not delay fracture treatment for this fracture type as progressive swelling can lead to more complications.

The major reason for open reduction in these cases is vascular compromise and therefore an anterior approach



Fig. 7 AP view – the fracture is now 3 weeks old and the periosteal reaction is well established. The fracture line is still present, but the pins can now be safely removed and active rom started



Fig. 9 AP view – the fracture is now 8 weeks postinjury and full ROM has been established



Fig. 8 Lateral view 3 weeks



Fig. 10 Lateral view 8 weeks

should be used. If you are not comfortable with this approach, you should take some time to familiarize yourself with this, as it will happen and it will most likely be at night.

References and Suggested Readings

Reynolds RA, Mirzayan R (2000) A technique to determine proper pin placement of crossed pins in supracondylar fractures of the elbow. *J Pediatr Orthop* 20(4):485–489

10 Cross-References

- ▶ [Supracondylar Humerus Fracture Extension Type: Cross Pinning](#)
- ▶ [Supracondylar Humerus Fracture Extension Type: Lateral Entry Pinning](#)

Supracondylar Humerus Fracture Extension Type: Lateral Entry Pinning

Oussama Abousamra and Christopher A. Iobst

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Abstract

A 5-year-old girl sustained an injury to her left elbow while playing on the trampoline. The elbow was swollen and deformed but was neurovascularly intact. Radiographic evaluation showed a displaced extension type supracondylar humerus fracture. The decision was made to admit to the hospital and proceed with closed reduction of the fracture in the operating room. Lateral entry pin fixation with three pins was performed. Radiographic evaluations were performed at 1 week and 4 weeks postoperatively. Pins were removed in the office at 4 weeks once healing was confirmed

radiographically. At 8 weeks postoperatively, our patient had full elbow range of motion with good alignment compared to the contralateral extremity.

1 Brief Clinical History

A 5-year-old girl was playing on the trampoline and fell on her left elbow. She had immediate pain and was not able to move her elbow. She had no numbness or tingling in her left hand or fingers. The elbow was swollen and deformed with no open wounds. The left hand was pink and warm, and the radial and ulnar pulses were palpable at the left wrist. There were no signs of motor deficits in the left hand.

The elbow injury was isolated with no associated injuries to the right upper extremity, lower extremities, head, chest, abdomen, or spine. Radiographs of the left elbow showed a displaced left distal humerus supracondylar fracture. The distal fragment was displaced posteriorly consistent with an extension type supracondylar humerus fracture. Since the injury was isolated, the decision was made to proceed with the orthopedic

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management of the fracture. Treatment options were discussed with the family including closed versus open reduction.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1

3 Preoperative Problem List

1. The left elbow injury was isolated with no associated injuries.
2. The patient was otherwise healthy with no chronic illnesses.

4 Treatment Strategy

Elbow supracondylar fractures are the most common elbow fractures in children (Frick and Mehlman 2017). The most common fracture pattern is the extension type fracture, in which the distal fragment is displaced posteriorly. Displacement has been described according to Gartland classification. Type I is a nondisplaced fracture; type II is an angulated fracture with an intact hinge posteriorly; and type III is a completely displaced fracture. A type IV has also been described and it indicates multidirectional instability with complete loss of periosteal continuity between the fragments, which is determined at the time of surgery.

Neurovascular exam of the involved extremity is a highly important part of the clinical examination in this type of fracture. Documentation in the chart of the neurovascular exam is essential

to guide later decisions. Radial pulse should be palpated at the wrist. Sensation should be assessed over the distribution of the radial, median, and ulnar nerves. Motor function of the radial nerve can be assessed by active thumb extension. The median nerve function can be assessed by thumb opposition to the index finger. The anterior interosseous branch of the median nerve is the most commonly injured nerve in extension type supracondylar fractures. This nerve function is tested by asking the patient to flex the interphalangeal joint of the thumb and/or the distal interphalangeal joint of the index finger. The ulnar nerve function can be assessed by active abduction and adduction (scissoring) of the fingers or crossing of the index and long fingers.

Different treatment methods are reported in the literature. Good outcomes have been reported after nonoperative treatment with closed reduction and elbow immobilization in flexion using a collar and a cuff (Blount's method) ((Muccioli et al. 2017), (Pham et al. 2017)). However, this requires elbow flexion greater than 90 degrees which increases the risk of compartment syndrome, and is not recommended. Therefore, the most commonly used method is closed reduction with percutaneous pinning across the fracture site. The pins create enough stability at the fracture site to allow the elbow to be extended to less than 90 degrees. Different pin configurations have been described and vary depending mainly on the surgeon's preference (Pesenti et al. 2017). Reduction stability, however, has been the most important factor in determining the final pin configuration intraoperatively.

In our patient, the decision was made to proceed with closed reduction in the operating room with full sterile setting and fixation with lateral percutaneous pinning. Neurovascular status should be documented and checked preoperatively and following reduction and pinning. Although in reports only 1.9% of the extension type fractures need open reduction

Fig. 1 (a, b): Anteroposterior and lateral radiographs of the left elbow showing a displaced extension type supracondylar fracture



(Flynn et al. 2017), this possibility should always be considered and discussed with the family. Open reduction is needed when closed reduction is not successful, most likely the result of soft tissue entrapment in the fracture site.

Postoperative complications include loss of satisfactory reduction, malunion, pin site infections, and compartment syndrome. In a multicenter study (Combs et al. 2016), the incidence of pin site infections after supracondylar humerus pinning was very low and estimated as 0.81%. Factors that could have contributed to the occurrence of these infections included preoperative antibiotic use, length of time the pins were left in, and cast change prior to pin removal (Combs et al. 2016). Every case of forearm pain postoperatively, even in the presence of a palpable radial pulse, should be approached with a high level of suspicion for compartment syndrome.

Closed reduction and percutaneous pinning of supracondylar fractures can be performed as an outpatient procedure, and the patient can go home the same day if there is no concern about the vascular supply or swelling of the extremity. Radiographs are taken at week 1 and week 3 or 4 postoperatively to monitor maintenance of reduction, pins location, and bone healing. Once the radiographs at week 3 or 4 show satisfactory healing, the pins are removed in the office. No further immobilization is needed and elbow motion is encouraged. The patient remains out of contact sports and strenuous activities that involve the upper extremity for 4 more weeks. Range of motion and elbow alignment is checked at a later clinic visit around 6-8 weeks after pin removal.

5 Basic Principles

1. General evaluation of the patient is necessary to rule out associated injuries.
2. Neurovascular examination of the injured extremity is highly important and should be documented.
3. The forearm should be examined to assess whether the compartments are soft and there are no signs of swelling. These injuries should be approached with a high suspicion for compartment syndrome.
4. The wrist is evaluated for possible distal both bone forearm fracture and a floating elbow injury.
5. Temporary immobilization in a splint helps provide comfort to the patient during transport and preoperative assessment, typically in about 30 degrees of elbow flexion.
6. The entire arm should be prepped in the sterile field in cases where reduction is predicted to be challenging, and open reduction may be needed.
7. The reduction maneuver under anesthesia starts with applying traction on the arm with the elbow in around 15 degrees of flexion.
8. Under fluoroscopy guidance, the fracture is reduced in the coronal plane with varus-valgus correction as needed.
9. A milking maneuver is helpful if the proximal fragment has penetrated the brachialis muscle. This maneuver includes milking the biceps and brachialis muscles in a proximal to distal direction to free the brachialis from the proximal fragment of the humerus. The maneuver should result in a palpable release of the humerus posteriorly through the brachialis.
10. Then, flexion of the elbow is performed with the surgeon's thumb placed under the olecranon to help push the distal fragment anteriorly with elbow flexion.
11. With the elbow in flexion, the whole arm will be turned as one unit with shoulder external rotation to obtain a lateral view on imaging. Another option to obtain the lateral view is to rotate the C-arm unit under the elbow. Rotating the c-arm is preferable in unstable fractures.
12. Initially, two lateral pins are placed and should be divergent and separated at the fracture site.
13. Whenever there is doubt about reduction stability, a third pin can be placed.
14. A slight translation or malrotation can be acceptable to avoid open reduction.
15. Very little coronal malalignment or sagittal angulation can be accepted. As a general rule the distal fragment should not be in varus, and the anterior humeral line should at least touch the ossified capitellum.
16. The stability of reduction is assessed under live fluoroscopic imaging. Attempted external rotation of the distal fragment will effectively test the strength of the fixation.
17. Following satisfactory reduction and fixation, the elbow is immobilized in less than 90 degrees of flexion to avoid compartment syndrome.
18. Radial pulse and hand perfusion should be checked at the end of the case and documented.

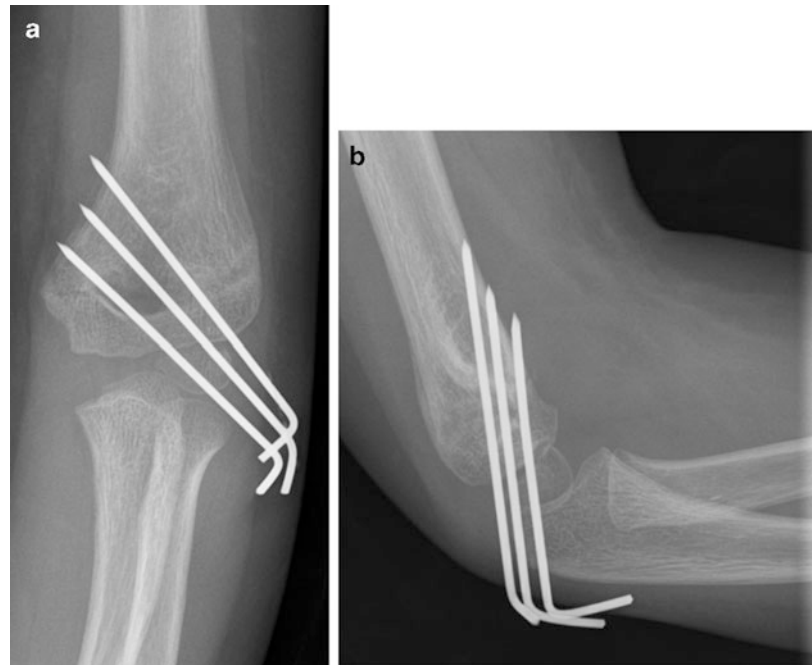
6 Technical Pearls

1. The extremity is prepped and draped in a sterile environment with the patient in the supine position.
2. Fluoroscopic imaging is needed for intraoperative reduction assessment.

7 Outcome Clinical Photos and Radiographs

See Fig. 2

Fig. 2 (a, b) Anteroposterior and lateral radiographs of the left elbow showing the fracture well reduced with internal fixation using pins



8 Avoiding and Managing Problems

1. Satisfactory reduction and alignment should be obtained. If the reduction is unstable, lateral imaging views can be obtained by rotating the fluoroscopic C-arm machine.
2. The lateral pins should always aim to be divergent and should never cross at the fracture site.
3. Satisfactory stability at the fracture site should be achieved and adding a third pin can be necessary.

9 Cross-References

- [Supracondylar Humerus Fracture Extension Type: Cross Pinning](#)
- [Supracondylar Humerus Fracture Flexion Type](#)

References and Suggested Reading

- Combs K, Frick S, Kiebzak G (2016) Multicenter study of pin site infections and skin complications following pinning of pediatric supracondylar humerus fractures. *Cureus* 8(12):e911
- Flynn K, Shah AS, Brusalis CM, Leddy K, Flynn JM (2017) Flexion-type supracondylar humeral fractures: ulnar nerve injury increases risk of open reduction. *J Bone Joint Surg Am* 99(17):1485–1487
- Frick SL, Mehlman CT (2017) The community orthopaedic surgeon taking trauma call: pediatric supracondylar humeral fracture pearls and pitfalls. *J Orthop Trauma* 31(6):11–15
- Muccioli C, ElBatti S, Oborocianu I, Rosello O, Solla F, Chau E, et al (2017) Outcomes of Gartland type III supracondylar fractures treated using Blount's method. *Orthop Traumatol Surg Res*. Available from: <https://doi.org/10.1016/j.otsr.2017.06.011>
- Pesenti S, Ecalle A, Gaubert L, Peltier E, Choufani E, Viehweger E et al (2017) Operative management of supracondylar humeral fractures in children: comparison of five fixation methods. *Orthop Traumatol Surg Res* 103(5):771–775
- Pham T-T, Accadbled F, Abid A, Ibnoukhatib A, Bayle-Iniguez X, Wargny M, et al (2017) Gartland types IIB and III supracondylar fractures of the humerus in children: is Blount's method effective and safe?. *J Shoulder Elbow Surg*. Available from: <https://doi.org/10.1016/j.jse.2017.05.018>

Supracondylar Humerus Fracture Extension Type: Cross Pinning

Oussama Abousamra and Christopher A. Iobst

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Abstract

A 5-year-old boy fell from a stool and sustained a left elbow injury. Radiographic evaluation showed a displaced supracondylar fracture of the left elbow. The fracture was closed reduced intraoperatively, and the decision to place two crossed pins was made based on the surgeon's preference. Although the most commonly used pins configuration is the lateral entry pins, certain fracture patterns or surgeon preference may dictate that crossed pins need to be used.

Follow up visits and radiographic evaluations at 1 week and 4 weeks postoperatively showed the fracture well be aligned with routine healing. The pins were removed at 4 weeks postoperatively and the cast discontinued. At 6 weeks follow up visit, the range of motion was evaluated. The patient demonstrated a full elbow range of motion, and no malalignment was seen.

1 Brief Clinical History

A 5-year-old boy fell on his left elbow and had left elbow pain and swelling. There were no open wounds on the elbow. He did not have motor deficits or altered sensation in his left hand and fingers. The left hand was well perfused and the radial pulse was palpated at the wrist. The injury was isolated and no associated injuries to the right upper extremity or lower extremities were detected. The treatment options including closed reduction and casting, closed reduction and percutaneous pinning, and open reduction with pinning were discussed with the family.

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2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. The left elbow injury was isolated.
2. There were no associated injuries to the right upper extremity, lower extremities, head, chest, pelvis, or spine.
3. The patient was otherwise healthy with chronic illnesses.

4 Treatment Strategy

Management of supracondylar humerus fractures has moved away from closed reduction and cast immobilization to closed reduction and pinning in most centers. While it is possible to reduce a supracondylar fracture and place it in a cast, the amount of flexion necessary to maintain the reduction creates a high risk of compartment syndrome. Therefore, most clinicians prefer to manage these injuries in the operating room.

Neurovascular examination of the injured extremity is highly important and should be documented. Radial pulse should be palpated at the wrist. Sensation of the hand is assessed over the distribution of the ulnar, median, and radial

nerves. Motor function of the radial nerve is assessed by the active thumb extension movement. Median nerve function is assessed by the thumb to index opposition movement. Ulnar nerve function is assessed by the active abduction and adduction (scissoring) of the fingers.

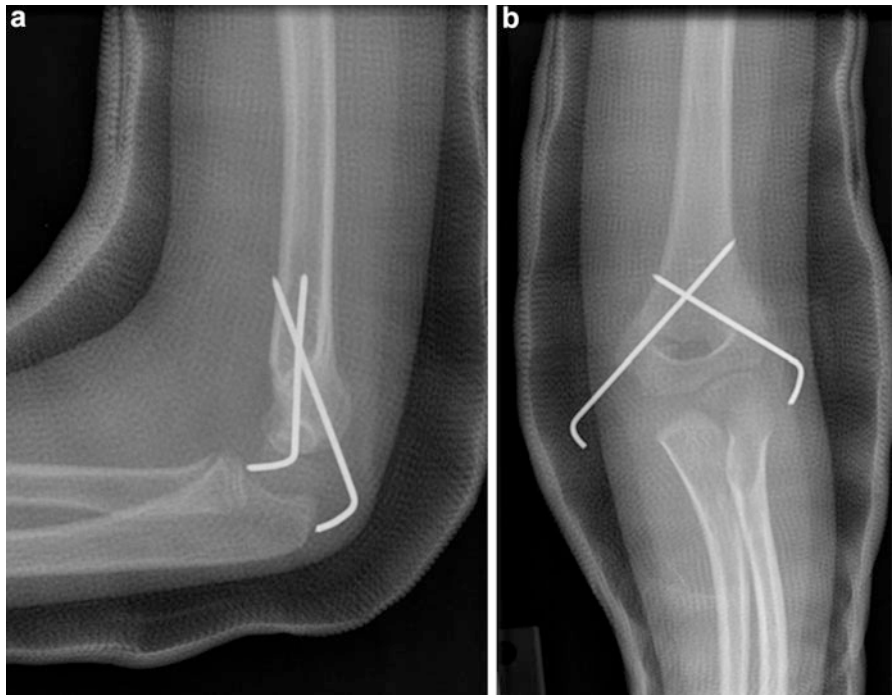
Different pin configurations have been described in the treatment of elbow supracondylar fractures (1). Although the decision depends mainly on the surgeon's preference, the final pin configuration is decided intraoperatively when fixation stability is assessed. Certain fracture patterns (oblique or comminuted supracondylar fractures) dictate the optimal pin configuration that is necessary. Traditionally, cross pinning was the most commonly used method for pinning supracondylar humerus fractures. The construct provides excellent fracture stability, especially to rotational forces, and typically only requires the surgeon to place two pins. However, as the technique of lateral entry pinning has been refined, most surgeons currently prefer the lateral entry technique over the cross pinning technique. The disadvantage of the cross pin technique is that it requires the surgeon to place a medial pin starting in the vicinity of the ulnar nerve. Surgeons are willing to place additional pins from the lateral entry position to increase the construct stability rather than risk causing an iatrogenic ulnar nerve injury with a medial pin. Nevertheless, every pediatric orthopedic surgeon should know how to place a medial pin safely in case it is necessary.

In our patient, the decision to proceed with cross pinning was made based on surgeon's preference. The procedure is

Fig. 1 (a, b) Anteroposterior and lateral radiographs of the left elbow showing a displaced extension type supracondylar fracture



Fig. 2 (a, b) Anteroposterior and lateral radiographs of the left elbow showing the fracture well reduced with internal fixation using pins



performed as an outpatient procedure in the operating room with full prepping and draping of the extremity in case an open reduction is required. Neurovascular evaluation of the extremity is highly important pre- and postoperatively to rule out ulnar nerve injury. Apart from iatrogenic ulnar nerve palsy, complications are similar to lateral pinning and include infection, loss of reduction, and compartment syndrome.

Clinic follow up visits are scheduled at 1 week and 4 weeks, postoperatively. Once fracture healing and alignment are satisfactory, pins are removed in the office. A later visit at around 6–8 weeks is scheduled to assess elbow alignment and range of motion.

5 Basic Principles

1. Evaluation of the patient's other extremities and systems is necessary to confirm that the extremity injury is isolated, or to identify other injuries.
2. Examination of the neurovascular status of the injured extremity is performed and documented pre- and postoperatively to rule out vascular injury and ulnar nerve injury.
3. As with all supracondylar fractures, any forearm pain should be approached with a high suspicion for compartment syndrome or secondary injury. Always look for the possibility of a second fracture in the wrist or forearm (floating elbow). These patients are especially at high risk for compartment syndrome.
4. Immobilization in a splint provides temporary relief and comfort for the patient before the procedure is performed.

6 Technical Pearls

1. The extremity is prepped and draped with the patient in the supine position.
2. Fluoroscopic imaging is needed and should be placed in a location that is comfortable for the surgeon and the team. The arm could be placed on an arm board or the C-arm could be flipped and the arm placed on it, this increases radiation dosage to everyone in the room.
3. The possibility of open reduction should be considered; therefore, the entire arm is prepped and draped.
4. The lateral pin is placed first to provide some stability at the fracture site.
5. Then, the elbow can be extended to approximately 45–60 degrees. Extending the elbow minimizes the tendency for the ulnar nerve to sublux anteriorly, which can cause the nerve to be draped over the medial pin or become tethered by the pin. The surgeon can then palpate the ulnar nerve and pull it posteriorly with a finger. This will move the nerve out of the way and protect the nerve while the pin is inserted percutaneously into the medial epicondyle.
6. If the arm is swollen and the medial epicondyle is difficult to palpate, a small medial incision can be made. The surgeon can then carefully dissect down to bone so the pin can be placed directly on bone to minimize ulnar nerve injury.
7. Two lateral pins can be placed if needed to achieve a stable fixation.

8. A slight translation or malrotation can be accepted to avoid open reduction.
9. Very little coronal malalignment or sagittal angulation can be accepted.
10. The stability of reduction is assessed under live fluoroscopic imaging.
11. The elbow is immobilized in less than 90 degrees of flexion to avoid compartment syndrome.
12. Radial pulse and vascular supply should be checked and documented.
3. A small medial incision helps placing the pin directly on bone to avoid ulnar nerve injury.
4. The lateral pin or two can be placed first to obtain provisional fixation. Then, the elbow can be extended to minimize the risk of ulnar nerve injury by the medial pin.

7 Outcome Clinical Photos and Radiographs

See Fig. 2.

8 Avoiding and Managing Problems

1. If the reduction is unstable, lateral imaging views can be obtained by rotating the fluoroscopic C-arm machine.
2. The pins should never cross at the fracture site. Two divergent lateral pins, in addition to the medial pin, could be used to achieve stability.

9 Cross-References

- [Supracondylar Humerus Fracture Extension Type: Lateral Entry Pinning](#)
- [Supracondylar Humerus Fracture Flexion Type](#)

References and Suggested Readings

- Larson L, Firoozbakhsh K, Passarelli R, Bosch P (2006) Biomechanical analysis of pinning techniques for pediatric supracondylar humerus fractures. *J Pediatr Orthop* 26(5):573–578
- Omid R, Choi PD, Skaggs DL (2008) Supracondylar humeral fractures in children. *J Bone Joint Surg Am* 90(5):1121–1132
- Pesenti S, Ecalle A, Gaubert L, Peltier E, Choufani E, Viehweger E et al (2017) Operative management of supracondylar humeral fractures in children: comparison of five fixation methods. *Orthop Traumatol Surg Res* 103(5):771–775

Supracondylar Humerus Fracture Flexion Type

Oussama Abousamra and Christopher A. Iobst

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Abstract

An 8-year-old boy sustained an injury to his left elbow while playing on the playground. Left elbow radiographs showed a distal humerus supracondylar fracture with the distal fragment translated anteriorly indicating a flexion-type supracondylar injury. The injury was isolated, and the neurovascular exam (with special attention to the ulnar nerve) was normal. Ulnar nerve palsy can be present in around 10% of flexion-type fractures. The decision was made to proceed with closed reduction and percutaneous pinning. The need for a possible open reduction was

discussed with the family since a higher risk for open reduction has been reported with flexion-type fractures. In our case, the fracture was closed reduced with placement of three percutaneous lateral pins. The patient was discharged home later the same day after checking the neurovascular status of his left upper extremity. Radiographic follow-up evaluations were performed at 1 week and 4 weeks postoperatively. Once healing was confirmed, pins were removed and the cast discontinued. At the 8-week clinic visit, he had full range of motion of his left elbow with no malalignment.

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1 Brief Clinical History

An 8-year-old boy was playing on the playground and fell directly on his left elbow. He had pain in his elbow with no ability to move the elbow. There was no numbness or tingling in his left hand or fingers. The elbow was swollen with no open wounds. There were no signs of motor deficits in the left hand. The left hand was pink and warm, and the radial and ulnar pulses were palpable at the left wrist.

There were no associated injuries to the right upper extremity, lower extremities, head, chest, abdomen, or spine. Radiographs of the left elbow showed a displaced left distal humerus supracondylar fracture. Since the injury was isolated, the decision was made to proceed with the orthopedic management of the fracture. Treatment options were discussed with the family.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. The patient was otherwise healthy with no chronic illnesses.
2. Left flexion-type supracondylar humerus fracture.

4 Treatment Strategy

Flexion-type supracondylar humerus fractures are rare injuries that have been estimated as 3.4% of total supracondylar humerus fractures in children (Flynn et al. 2017). A higher risk of the need for open reduction has been reported with flexion-type fractures (Flynn et al. 2017; Novais et al. 2016). Ulnar nerve palsy can be present in around 10% of cases (Flynn et al. 2017). For these fractures, the most commonly used method of treatment is closed reduction

with percutaneous pin fixation. Lateral only or lateral and medial pins configuration can be used to achieve stability.

Neurovascular exam of the involved extremity is an important part of the clinical examination in this type of fractures with special attention to the ulnar nerve. Neurovascular status should be documented and checked both preoperatively and following reduction and pinning. The possible need for an open reduction should be discussed with the family.

Possible postoperative complications include loss of reduction, malunion, pin site infections, and compartment syndrome. The incidence of pin site infections after supracondylar humerus pinning is estimated as 0.81% (Combs et al. 2016). Preoperative antibiotics use, length of time the pins are left in, and cast change prior to pin removal can be considered among the factors that contribute to infections (Combs et al. 2016). Postoperative forearm pain should be approached with a high suspicion for compartment syndrome.

When closed reduction is difficult and requires multiple attempts with different maneuvers, it is recommended that the patient stays overnight after the procedure for neurovascular checks. Postoperative radiographic evaluations are needed in this type of fractures to monitor maintenance of reduction. In unstable fractures that require difficult reduction, pins removal might be deferred until week 6 postoperatively. Once the radiographs show satisfactory healing, the pins are removed and elbow motion encouraged. The patient needs to avoid strenuous activity on the upper extremities for 4 more weeks. Another clinic visit around 8–10 weeks postoperatively might be needed to check the elbow alignment and range of motion.

Fig. 1 (a, b) Anteroposterior and lateral radiographs of the left elbow showing a displaced flexion-type supracondylar fracture



5 Basic Principles

1. General evaluation of the patient is necessary to rule out injuries to other extremities and other systems.
2. Documentation of the neurovascular examination is important in approaching these fractures, especially the ulnar nerve function.
3. A high level of suspicion for compartment syndrome is necessary throughout the evaluation and management of these injuries.
4. Splint or bivalved cast immobilization for comfort is needed during the preoperative time period.

6 Technical Pearls

1. The patient is positioned in the supine position, and the upper extremity is placed on a radiolucent arm board.
2. The extremity is prepped and draped in a fully sterile environment in case open reduction is needed.
3. Fluoroscopic imaging is used to assess intraoperative reduction.
4. A rolled towel placed under the proximal fragment will help with reduction of the flexed distal fragment.
5. With the elbow in around 45° of flexion, the fracture is reduced in the coronal plane with varus valgus maneuvers (Chukwunyerenna et al. 2016).
6. The C-arm should be rotated in the sagittal plane to obtain lateral views and to prevent loss of reduction in unstable fractures with external rotation to get the lateral view.
7. A joystick pin can help reduce the distal fragment.

8. When the reduction is satisfactory, the first pin can be advanced with fluoroscopic guidance on the lateral view.
9. Usually, three pins are needed to secure a stable fixation. A medial pin could be used if necessary to obtain stable fixation.
10. A slight translation or malrotation can be acceptable to avoid open reduction; however, no or only very little varus displacement in the coronal plane should be accepted.
11. The stability of reduction is assessed under live fluoroscopic imaging.
12. Elbow immobilization in flexion less than 90° is performed once satisfactory reduction and stability were achieved.
13. Radial pulse and hand perfusion should be checked and documented.

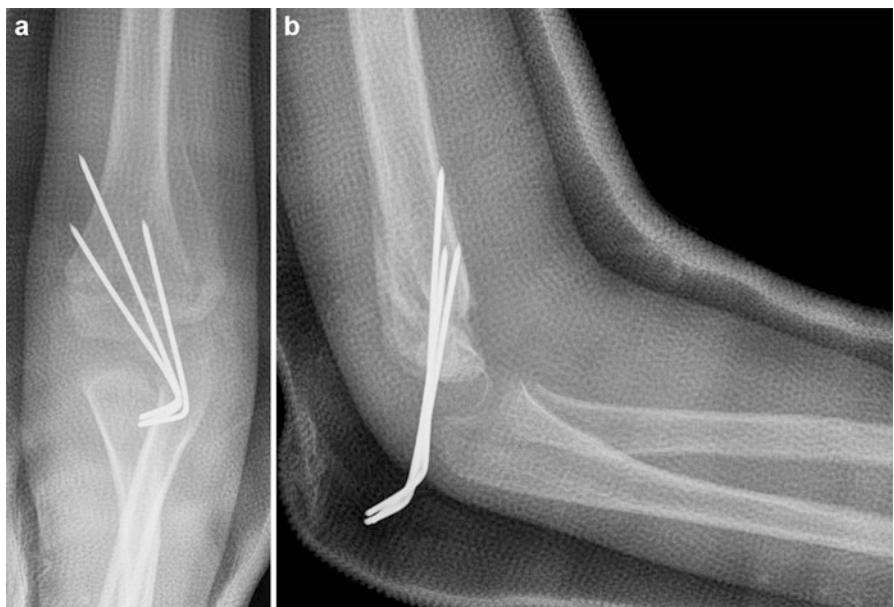
7 Outcome Clinical Photos and Radiographs

See Fig. 2.

8 Avoiding and Managing Problems

1. Rotating the fluoroscopic C-arm machine to obtain the lateral view images (rather than rotating the arm) is helpful in difficult reductions.
2. The pins should separate and never cross at the fracture site.
3. The distal fragment might need to be captured with a pin that can be used as a joystick to help in reduction.

Fig. 2 (a, b) Anteroposterior and lateral radiographs of the left elbow 4 weeks postoperatively showing the fracture well reduced with internal fixation using pins



9 Cross-References

- [Supracondylar Humerus Fracture Extension Type: Cross Pinning](#)
- [Supracondylar Humerus Fracture Extension Type: Lateral Entry Pinning](#)

References and Suggested Readings

Chukwunyeremwa C, Orlik B, El-Hawary R, Logan K, Howard JJ (2016) Treatment of flexion-type supracondylar fractures in children:

the “push-pull” method for closed reduction and percutaneous K-wire fixation. *J Pediatr Orthop B* 25(5):412–416

Combs K, Frick S, Kiebzak G (2016) Multicenter study of pin site infections and skin complications following pinning of pediatric supracondylar humerus fractures. *Cureus* 8(12):e911

Flynn K, Shah AS, Brusalis CM, Leddy K, Flynn JM (2017) Flexion-type supracondylar humeral fractures: ulnar nerve injury increases risk of open reduction. *J Bone Joint Surg Am* 99(17):1485–1487

Novais EN, Carry PM, Mark BJ, De S, Miller NH (2016) Posterolaterally displaced and flexion-type supracondylar fractures are associated with a higher risk of open reduction. *J Pediatr Orthop B* 25(5):406–411

Open Treatment of Supracondylar Humerus Fractures

Ryan Colley and Christopher A. Iobst

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Abstract

Supracondylar humerus fractures are one of the most common pediatric orthopedic injuries and make up 50–70% of children's fractures about the elbow. The majority of these fractures can be treated with closed manipulation and casting or percutaneous pin fixation. Occasionally, these fractures need to be treated by open means. The indications, timing, need, and approach to open treatment of these injuries are not always

straightforward. Typical indications for open treatment include an irreducible fracture, an open fracture, a vascular injury, or a nerve injury following reduction. This case highlights the management strategies for a 6-year-old with a type III supracondylar humerus fracture and associated vascular injury.

1 Brief Clinical History

A 6-year-old female was bounced off of a trampoline and landed on an outstretched arm. Upon presentation to the emergency department, she had an obvious deformity about the elbow. There was skin puckering in the antecubital fossa with surrounding ecchymosis (Fig. 1). Neurologic exam revealed an inability flex the interphalangeal joint of her thumb. The radial pulse was neither palpable nor detectable with Doppler ultrasound. The hand was pale and cool to touch. Radiographs revealed an extension type IIIB supracondylar humerus fracture (Figs. 2 and 3).

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Fig. 1 Demonstration of brachialis sign

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

1. Type IIIB supracondylar humerus fracture
2. Dysvascular extremity
3. Anterior interosseous nerve neurapraxia

4 Treatment Strategy

Initial assessment of the patient should include evaluation for any other injuries. Orthogonal radiographs of the humerus, elbow, and forearm should be obtained to delineate fracture pattern and identify any other concomitant fractures. Fractures of the ipsilateral distal radius can occur in 5–10% of children and are associated with a higher rate of compartment syndrome (Sawyer and Spence 2017). This patient was determined to have an isolated injury. Initial management in the emergency department should include gentle repositioning of the arm into a position of relative flexion to try to improve distal perfusion. The arm should be splinted and the vascular status reassessed. If the hand remains avascular, emergent surgical intervention is necessary (Mooney et al. 2016). Our patient was repositioned into flexion and a long arm posterior splint was placed. Vascular status was unchanged after splinting. The patient was taken to the operating room emergently, and the vascular surgeon was notified of the possible need for vascular repair.



Picture compliments of Steven Frick, MD

Fig. 2 Preoperative AP radiograph



Fig. 3 Preoperative lateral radiograph

In the operating room, the patient should be placed supine on a radiolucent bed with a radiolucent hand table. The arm is centered on the hand table and the patient is brought to the edge of the bed. The arm is then prepped and draped free in a sterile fashion. The fluoroscopy machine should be positioned at the head of the patient, perpendicular to the hand table. The surgeon stands at the end of the hand table, and an assistant stands in the patient's axilla.

If skin puckering over the anterior distal humerus is present, then buttonholing of the proximal spike through the brachialis muscle has occurred. This can block reduction, and the brachialis should be “milked” out of the fracture site. This can be accomplished using the “milking maneuver” (Archibeck et al. 1997) or by wrapping an Esmarch tourniquet from the shoulder to the

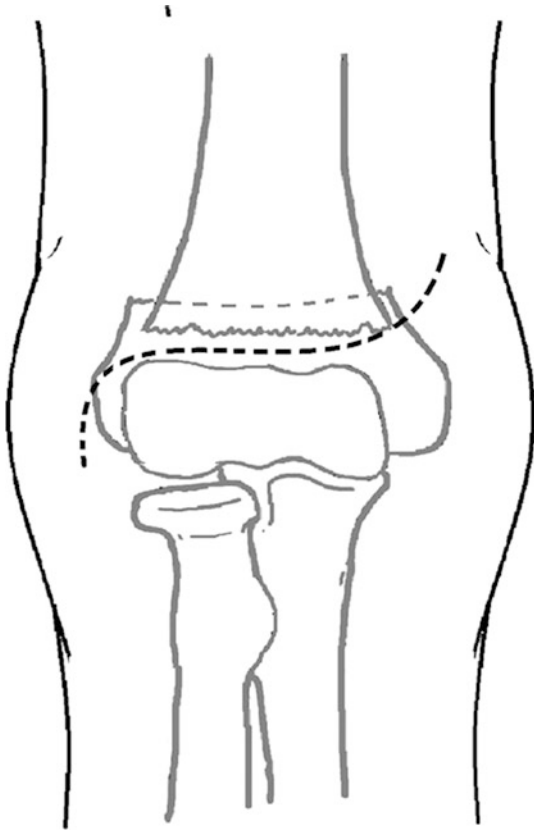


Fig. 4 Incision for anterior approach to distal humerus

elbow. Closed reduction is performed utilizing in-line traction, correction of coronal plane alignment, and elbow hyperflexion with posterior to anterior pressure placed on the olecranon.

In this case, the lateral fluoroscopic view revealed the fracture was over-reduced into flexion. A small stack of towels was placed beneath the arm just proximal to the fracture site to allow fine tuning of the reduction. Once adequate reduction was obtained, three lateral entry Kirschner wires were placed for temporary fixation. The vascular status was reassessed, and the arm was found to be persistently dysvascular with pale color to the hand and no distal pulses detectable with the Doppler. Consequently, it was decided that vascular exploration was necessary and the vascular surgeon was notified.

An anterior approach to the distal humerus was used. A “lazy S” incision (Fig. 4) was drawn on the skin with the transverse limb in the elbow flexion crease. The transverse incision was used initially with the proximal medial and distal lateral extensions used for increased exposure as needed (Fig. 5). Blunt dissection was carried lateral to the biceps tendon with the majority of the dissection completed by the initial trauma. The brachialis was identified trapped in the fracture site. The median nerve was found to be intact but on



Fig. 5 Anterior approach to distal humerus

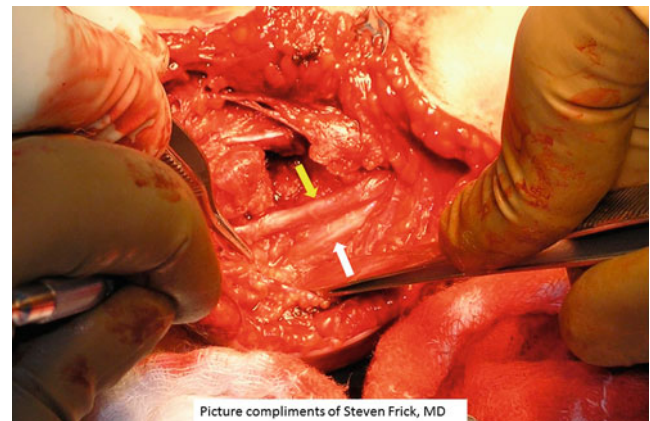


Fig. 6 Intraoperative view of brachial artery (yellow arrow) and median nerve (white arrow)

stretch over the fracture (Fig. 6). A freer was used to extract the brachialis and gently lever the fracture out to length. The fracture was reduced using a combination of posterior pressure on the proximal fragment, traction, and flexion of the elbow with direct pressure on the olecranon (Fig. 7). Definitive fixation using three lateral entry 0.062 Kirschner wires was performed percutaneously outside the incision utilizing fluoroscopic guidance (Figs. 8, and 9). After fracture stabilization, the brachial artery was inspected and found to be injured. Vascular surgery repaired the artery with a patch graft. Distal perfusion was confirmed and the patient had good capillary refill. The wound was irrigated, closed, and placed in a posterior splint at 45° of flexion with confirmation that pulses were maintained. The patient was transferred to the ICU for hourly Doppler exams and clinical monitoring.



Fig. 7 Final incision



Fig. 8 Intraoperative AP fluoroscopic view

5 Basic Principles

The majority of supracondylar humerus fractures can be managed closed. Typical indications for open treatment include irreducible fracture, neurovascular compromise, or open fracture.

The following general guidelines should be used in the management of a supracondylar humerus fracture with vascular compromise. The patient with no pulses at the wrist but a well-perfused hand (pink, pulseless hand) can be splinted and closely observed until the most appropriate operating room staff can be assembled. If the hand is pale and cool to the touch and pulses are not detectable with Doppler

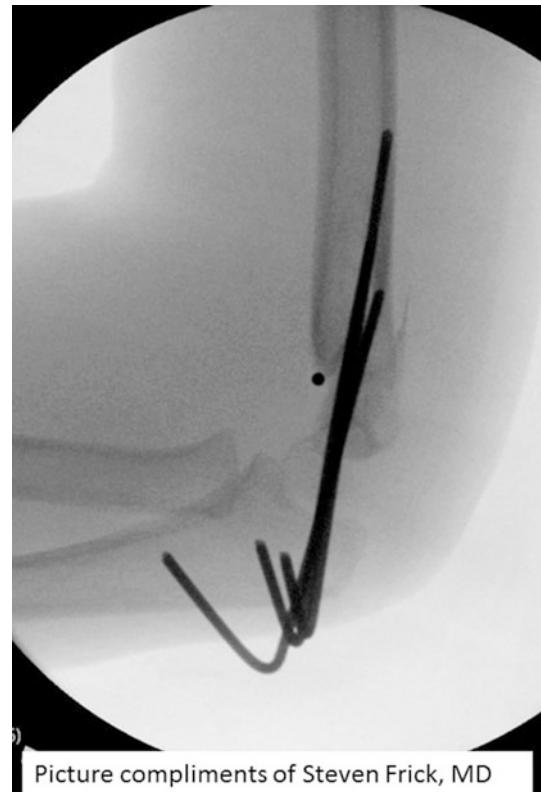


Fig. 9 Intraoperative lateral fluoroscopic view

ultrasound (white, pulseless hand), emergent surgical intervention is necessary (Wingfield et al. 2015). Since the area of vascular injury is known, angiograms are usually not necessary, and waiting to obtain a vascular study should not cause a delay in treatment. After reduction and fixation of the fracture, the hand that appears perfused but with persistently absent pulses requires clinical judgment. Recommendations for this situation range from immediate vascular exploration to splinting and close monitoring for 24 h. The elbow has rich collateral circulation that allows the extremity to remain perfused despite brachial artery disruption.

6 Images During Treatment

See Figs. 4, 5, 6, and 7.

7 Technical Pearls

The milking maneuver can be used to free the proximal fragment from within the brachialis muscle (Archibeck et al. 1997). To perform this maneuver, countertraction is gently applied, and the anterior musculature of the arm is grasped proximally between the thumb and fingers. The muscle mass is then milked

distally by using firm pressure applied anterolaterally to avoid the medial neurovascular structures. Freeing of the brachialis muscle is indicated by a palpable sudden release or audible “pop,” followed by a marked increase in fracture-fragment mobility. Alternatively, using an Esmarch bandage wrapped from proximal to distal can often help to milk the brachialis from the fracture site and help facilitate closed reduction.

Some authors advocate making the surgical approach to the distal humerus based on the direction of displacement. A medial approach can be used for a flexion type or a posterolaterally displaced fracture to allow exploration of the median and ulnar nerves. A lateral approach can facilitate exploration of the radial nerve in posteromedial displacement. An anterior approach, however, is the most utilitarian and can be used in most fracture types (Mencio 2015). No matter the approach, careful blunt dissection should be utilized as the neurovascular structures are often displaced from their anatomic positions.

These fractures are often very unstable in hyperflexion. A small towel can be placed posteriorly proximal to the fracture site and the elbow maintained at 90° of flexion to fine tune the reduction.

In particularly unstable fractures or with limited surgical help, wires can be driven in a retrograde fashion up to the fracture site and used as joystick to facilitate fracture reduction. Once adequate reduction is achieved, the pins can be advanced into the proximal fragment.

8 Outcome Clinical Photos and Radiographs

See Figs. 8 and 9.

9 Avoiding and Managing Problems

Do not become distracted by the obvious deformity and injury. Ensure careful clinical and radiographic evaluation above and below the fracture as a missed concomitant frac-

ture can be easily overlooked. Do not forget the axiom, “the most commonly missed fracture on a radiograph is the second fracture.”

As soon as vascular compromise is recognized, it is important to ensure that adequate vascular surgical support is available and equipped to handle these vascular injuries. They should be notified early if exploration is possible.

Most neurologic injuries are the result of neurapraxia and can be managed with clinical monitoring. If the neurapraxia persists beyond 12 weeks, then EMG is indicated (Sawyer and Spence 2017).

10 Cross-References

- [Oblique Supracondylar Humerus Fracture](#)
- [Supracondylar Humerus Fracture Extension Type: Cross Pinning](#)
- [Supracondylar Humerus Fracture Extension Type: Lateral Entry Pinning](#)
- [Supracondylar Humerus Fracture Flexion Type](#)

References and Suggested Readings

- Archibeck MJ, Scott SM, Peters CL (1997) Brachialis muscle entrapment in displaced supracondylar humerus fractures: a technique of closed reduction and report of initial results. *J Pediatr Orthop* 17(3):298–302
- Mencio GA (2015) Fractures and dislocations about the elbow. In: Swiontkowski MF (ed) *Green’s skeletal trauma in children*, 5th edn. Saunders, Philadelphia, pp 182–245
- Mooney JF, Hosseinzadeh P, Oetgen M, Cappello T (2016) AAOS appropriate use criteria: management of pediatric supracondylar humerus fractures with vascular injury. *J Am Acad Orthop Surg* 24(2):e24–e28
- Sawyer JR, Spence DD (2017) Fractures and dislocations in children. In: Azar FM, Beaty JH, Canale ST (eds) *Campbell’s operative orthopaedics*, 13th edn. Elsevier, Philadelphia, pp 1423–1569
- Wingfield JJ, Ho CA, Abzug JM, Ritzman TF, Brighton BK (2015) Open reduction techniques for supracondylar humerus fractures in children. *J Am Acad Orthop Surg* 23(12):e72–e80

T-Condylar Distal Humerus Fractures

Travis Frantz and Christopher A. Iobst

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Abstract

T-condylar distal humerus fractures are rare in children and represent only about 2% of pediatric elbow fractures (Maylahn and Fahey, J Am Med Assoc 166:220–228, 1958). During a hyperextension moment, the olecranon is “wedged” into the trochlea and generates a T-shaped fracture in the distal humerus (Re et al., *Pediatr Orthop* 19:313–318, 1999). Nonoperative management of these fractures is rarely an option, as the natural history of this injury without anatomic reduction results in stiffness, malunion, and chronic elbow malfunction. While

acceptable reduction can sometimes be obtained with closed reduction and percutaneous pinning (CRPP), this injury more commonly requires open reduction. The case below highlights the management strategies of T-condylar distal humerus fractures, including approach considerations, basic principles, technical pearls, and common problems encountered.

1 Brief Clinical History

A 13-year-old right-hand dominant male presented to the hospital after a fall from standing directly onto a flexed right elbow. He had acute onset of pain and immediately went to the emergency department for further care. He was noted to have no signs of open fracture and was fully neurovascularly intact without deficits. The injury was isolated to the right elbow without other musculoskeletal complaints.

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2 Preoperative Clinical Photos and Radiographs

Right elbow radiographs depicting T-condylar distal humerus fracture on the (A) anterior posterior (AP) view, (B) lateral view, and (C) traction view.



3 Preoperative Problem List

1. Left/right T-condylar distal humerus fracture.
2. Skeletally immature.
3. Soft tissue swelling.

4 Treatment Strategy

Treatment of this injury, as with any traumatic injury, should begin with appropriate resuscitation and assessment of other injuries. Attention should be given to the radius and ulna, particularly distally, as a “floating elbow” is possible. Mechanism of injury is important to consider, as it may result in an increased risk of compartment syndrome. The elbow should be assessed for open wounds, and as with supracondylar or other pediatric elbow fractures, it is important to document a clear neurovascular exam. If the injury is open, then management consists of appropriate intravenous (IV) antibiotics, tetanus coverage, and irrigation and debridement of the wound. Following these steps, or if the injury is closed, a well-padded splint should be placed for temporary stabilization.

Preoperative imaging is important in these injuries, and if possible, plain x-rays should be obtained prior to splint placement. Anteroposterior (AP), lateral, and oblique (internal and external) views can all aid in the diagnosis. If shortening is present, a traction radiograph can be helpful as well. However, in the authors’ experience, this is poorly tolerated in patients, particularly the pediatric population, and computed tomography (CT) is more preferred. Advanced imaging helps to provide a more detailed analysis of the fracture anatomy including fractures in the coronal plane which can be underappreciated or missed.

There is little role for nonoperative management of this injury, as lack of anatomic restoration will result in a dysfunctional elbow in the long term. In the younger pediatric population, CRPP can sometimes achieve satisfactory alignment and is performed using the principles of supracondylar humerus fracture fixation. However, in our experience, an open procedure allows for direct visualization and a more anatomic reduction. The goal of operative fixation is to provide a stable, anatomic construct that allows for early range of motion (ROM) postoperatively (Wiesel 2016).

5 Basic Principles

We prefer positioning in the lateral position, with the arm laid over an arm board and flexed at 90 degrees. After the patient is prepped and draped sterilely, a long posterior midline incision is utilized (unless open injury dictates other location) from proximal to distal, curving just medial to the olecranon and down the ulnar shaft. It can be extended as needed. The fascia is then divided, and the ulnar nerve should be identified. It should be dissected free both proximally at the level of intermuscular septum and distally between the two heads of flexor carpi ulnaris (FCU) and the first motor branch. Careful attention should be paid to the ulnar nerve at all times.

Next a decision must be made regarding approach on how to best visualize the joint and fracture. Traditionally either an olecranon osteotomy or a Morrey slide should be performed. In brief, the Morrey slide elevates the triceps and ulnar periosteum off of the ulna medially to expose the distal humerus without requiring a full osteotomy (Bryan and Morrey 1982). It should be noted that a triceps splitting or triceps sparing/reflecting may also be utilized. With a triceps sparing approach, both medial and lateral windows can be used taking care to identify and protect the ulnar and radial nerves, respectively.

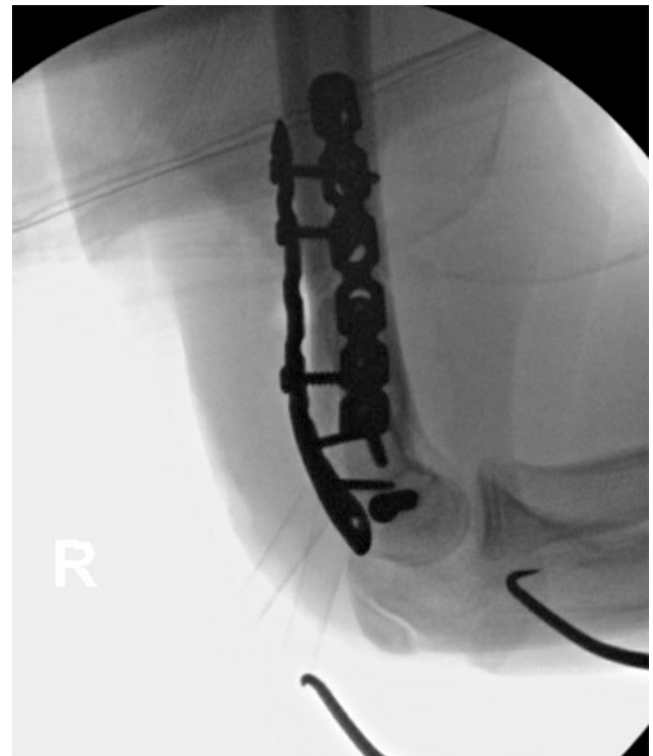
Fixation must be accomplished with articular reduction first. The condyles should be fixed to one another with Kirschner (K) wires and then subsequently to the shaft. Reduction tools and clamps can be utilized as needed, taking care to note the location of neurovascular structures. Once adequate reduction is obtained, then plating can be performed. We prefer bicolumnar plating and institute as many of the principles of distal humerus fracture fixation as possible (O’Driscoll 2005). While locking plate and screw construct are commonly used, it may not always be required in the younger pediatric population. Indications for a locking construct should be considered and only used if deemed necessary. However, in most cases, pre-contoured distal humeral plates will be locking in nature. It is worth emphasizing that the distal locking screws must engage the opposite column of bone, and this should be done after compressing with a large clamp. Sacrificing on this component will likely lead to construct failure (Green 2005). If not using a locking construct, then compression can be achieved through screw fixation by technique or design. The K wires should be removed once the plating is secured and reduction achieved.

If using the osteotomy or Morrey slide, then these are repaired accordingly, using suture, FiberWire, or hardware of the surgeon's preference. The ulnar nerve is not commonly transposed unless it is noted to be rubbing against the new hardware or subluxating during full elbow ROM. A drain can be placed if desired. Fascial and skin closure again per surgeon discretion, but we would recommend the use of nylon for the skin as it commonly allows for earlier ROM relative to other sutures.

External fixation can also be used as an alternative to plating. Once the articular surface of the distal humerus is reduced, cannulated screws can be used to maintain the reduction. The fixed articular fragment can then be reduced to the shaft fragment and held using a circular external fixator with half pins in the proximal segment and a combination of wires and half pins in the distal segment.

6 Images During Treatment

Intraoperative fluoroscopy demonstrating final bicolumnar plate construct on the A) AP view and B) lateral view.



7 Technical Pearls

Careful thought must be given to how to best visualize the joint during the procedure. If less visualization of the joint is required, then a less invasive triceps splitting or sparing approach may be sufficient. Olecranon osteotomies are well described and offer the maximum amount of joint visualization. However, it is thought that they should still be avoided if there is any thought to total elbow arthroplasty as a salvage procedure. In the pediatric population, a Morrey slide can be utilized to avoid making a full osteotomy (described briefly above) (Bryan and Morrey 1982).

The distal humerus is a hinge, with a middle articulation and a column both medial and lateral to this. This so-called triangle of stability must be recreated during T-condylar fixation. The articular surface should be reconstructed first. Frequently, this is less comminuted than in adults. There are commonly three large pieces – the medial condyle, the lateral condyle, and the humeral shaft. The condyles and articular surface should be reconstructed first, followed by reduction to the shaft (Wiesel 2016).

It is imperative that during placement of the distal locking screws that adequate reduction and compression be maintained. It is also essential that these screws are bicolumnar and reach the opposite column. Obtaining this

fixation with compression while maintaining anatomic reduction will allow for a stable construct capable of initiating early ROM (Green 2005).

8 Outcome Radiographs

Follow-up radiographs at 1 week on the A) AP view, B) lateral view. Follow-up radiographs at 3 months on the C) AP view and D) lateral view demonstrating healing.





9 Avoiding and Managing Problems

If the injury is open, a thorough and copious irrigation and debridement should be performed. Infected distal humerus hardware and subsequent repeat surgeries can have catastrophic effects on the pediatric elbow. If there is gross contamination, consideration must be given to multiple irrigations and temporary stabilization prior to proceeding with definitive fixation.

Before sterile prep and draping, the C-arm should be brought in to ensure adequate imaging can be obtained. Commonly repositioning of the patient or arm board will be needed. Recognizing this prior to beginning the case will be of great benefit.

As previously mentioned, preoperative CT can be quite helpful in determining the extent of comminution or a coronal split. This will aid in selecting the appropriate hardware and constructs.

This is a complicated and less common fracture pattern. It can be technically demanding, and as such we would recommend not performing this case in the middle of the night if possible. In the vast majority of cases, it would be beneficial to wait at least until the following morning to allow adequate time for preoperative planning as well as the addition of a full orthopedic surgical team. If the elbow is too swollen to operate acutely, then waiting 10–14 days is appropriate.

In regard to approach, the triceps splitting approach has improved outcomes and range of motion; however, this approach cannot be used if there is intra-articular comminu-

tion. Younger patients do appear to be more amenable to less invasive approaches such as triceps splitting or sparing. In comparison with the olecranon osteotomy with Morrey slide, osteotomy does have a higher rate of complications, and when present, these complications have a high likelihood of resulting in poor outcome (Anari et al. 2017).

Several different manufactures produce distal humerus plating systems, either bicolunar or 90:90 plating. Being familiar with the system(s) available, as well as the age, maturity, and fracture characteristics, will help in successfully achieving fixation. It is strongly recommended to be familiar with the hardware prior to proceeding with the surgery, and contacting the local manufacturing representative to ensure all necessary components are present is recommended.

Patients should be counseled clearly both pre- and post-operatively that they may not regain full elbow ROM. However, the surgeon should institute every measure possible to regain ROM without jeopardizing fracture fixation. Commonly this begins with early ROM protocols, some even advocating for immediate passive ROM (Beck et al. 2014). Specifically in the pediatric population, close follow-up is warranted as compliance can be an issue, resulting in stiffness or instability depending on the patient.

10 Cross-References

► T-Condylar Distal Humerus Fractures

References and Suggested Reading

- Anari JB, Neuwirth AL, Carducci NM, Donegan DJ, Baldwin KD (2017) Pediatric T-condylar Humerus fractures: a systematic review. *J Pediatr Orthop* 37:36–40
- Beck NA, Ganley TJ, McKay S, Tomlinson L, Ahn J et al (2014) T-condylar fractures of the distal humerus in children: does early motion affect final range of motion? *J Child Orthop* 8:161–165
- Bryan RS, Morrey BF (1982) Extensive posterior exposure of the elbow. A triceps-sparing approach. *Clin Orthop Relat Res* 166:188–192
- Green DP (2005) *Green's operative hand surgery*. Elsevier/Churchill Livingstone, Philadelphia
- Maylahn DJ, Fahey JJ (1958) Fractures of the elbow in children review of three hundred consecutive cases. *J Am Med Assoc* 166:220–228
- O'Driscoll SW (2005) Optimizing stability in distal humeral fracture fixation. *J Shoulder Elb Surg* 14:186S–194S
- Re PR, Waters PM, Hresko T (1999) T-condylar fractures of the distal humerus in children and adolescents. *J Pediatr Orthop* 19:313–318
- Wiesel SW (2016) *Operative techniques in orthopaedic surgery*. Wolters Kluwer, Philadelphia

Transphyseal Distal Humerus Fracture

Dalia Sepulveda

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Abstract

The Transphyseal Distal Humerus Fracture is a true Salter–Harris type I distal humerus epiphysiolysis, and it is a very rare trauma lesion usually occurring under the age of 2–3 years old. It is difficult to analyze the x-rays at this age because the distal region of the humerus is still not ossified. Since it is not a frequent fracture, it is a must for physicians in charge of primary emergency health care to be aware of non-accidental injuries as an important cause to rule out. Other reasons for this fracture are a fall from bed from a small height and in a newborn with an history of difficult delivery. It is very common that primary care physicians as well as radiologists miss the diagnosis at first visit, so it is very important to carefully evaluate any swollen elbow in a very young child who may have or have not a clear history of recent trauma. A good result after proper treatment relies in an adequate diagnosis based first in standard plain radiographs taken in a strictly AP and lateral views; today it is recommended also to use

ultrasound for the diagnosis. When the diagnosis is missed, it is likely that a cubitus varus may develop during follow up as the most frequent sequelae that will need a corrective surgery in future.

1 Brief Clinical History

This is the typical case of a healthy one and a half year old boy who fell from the high of his bed hitting his right elbow against concrete floor; he was first seen in the emergency room by a trauma surgeon who asked for AP and LAT x-ray projections. The radiologist reported no bone lesions and the surgeon treated him with a long arm splint with elbow flexed at 90° as if it was a contusion of elbow (Fig. 1).

After 3 days the parents came back to emergency because the child was in pain and the splint was in bad condition in this second visit the same surgeon asked for comparative right and left AP elbow x-rays; once more the diagnosis was missed although the father himself pointed out that he noticed a malalignment of the forearm relative to the arm. A new splint was made because the clinician diagnosed a non-displaced supracondylar fracture. The boy completed

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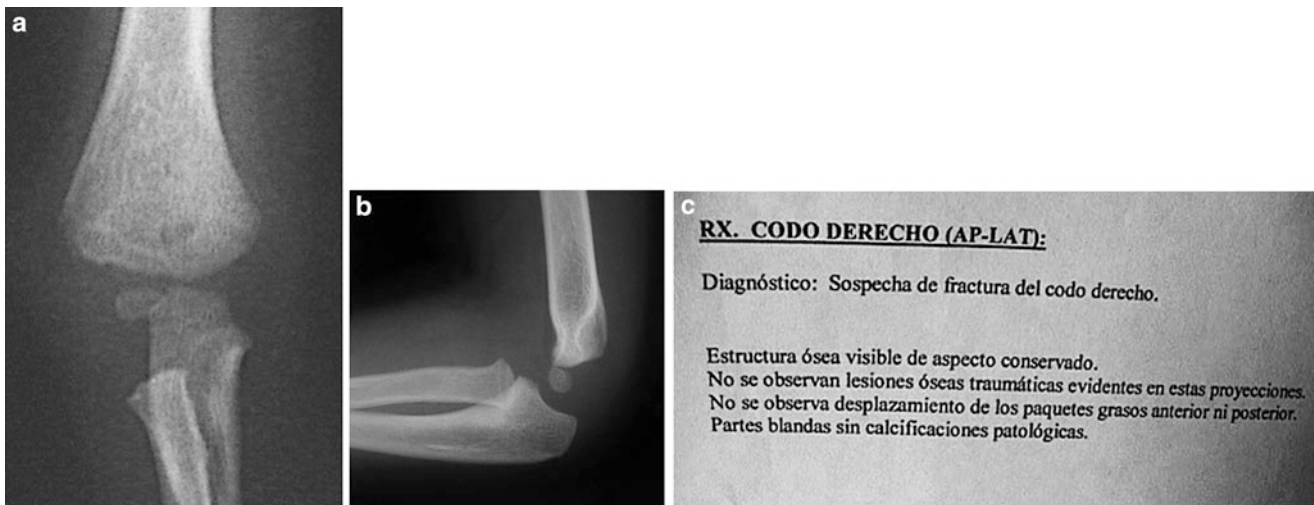


Fig. 1 (a–c) 1st x-rays AP-LAT projections

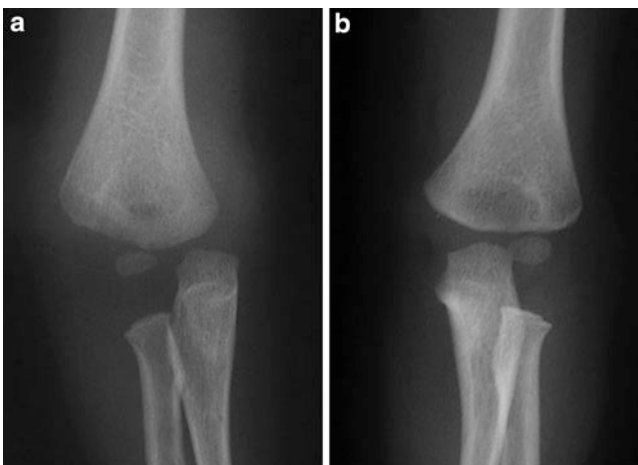


Fig. 2 (a–b) 2nd comparative x-rays AP projections

4 weeks of treatment and then underwent physical therapy for regaining flexion extension movement (Fig. 2).

2 Preoperative Clinical Photos and Radiographs

After 3 months, the parents were not happy with the elbow deformity, which instead of getting better as they were told it would happen, was progressively deforming in a varus direction; for this reason a new third set of x-rays were taken. The third diagnosis was a transphyseal separation not previously diagnosed, and a decision was made to wait a couple of years until the healing was complete and some remodeling occurs prior to osteotomy for realignment (Fig. 3).

3 Preoperative Problem List

Cubitus varus is the most frequent anatomical sequelae after supracondylar fracture, usually for malunion, but can be related to osteonecrosis of the trochlea or overgrowth after lateral condyle fracture. Newer studies report a poor natural history for cubitus varus, and often there is great concern from the parents regarding the angular deformity of the elbow. The forearm and hand tend to touch the body each time the child walks with a normal balance during gait.

3.1 Preop Concerns

- Small size of the distal humerus before 5–6-year-old
- Lateral distal approach should respect radial nerve
- Lack of internal stable implants other than K wires
- Chances of a new osteonecrosis if surgical approach is much aggressive
- No patient cooperation during postoperative procedures

4 Treatment Strategy

It is recommended that the malalignment osteotomy correction should be done over 5–6 years of age. In the past decade simpler external fixators had become a good solution for stable osteosynthesis, compared with larger approaches needed for internal fixators with the risk of osteonecrosis or instability with just Kirchner wires. The easiest approach is a distal anterior lateral incision protecting the radial nerve, and preserving carefully muscles and periosteum.

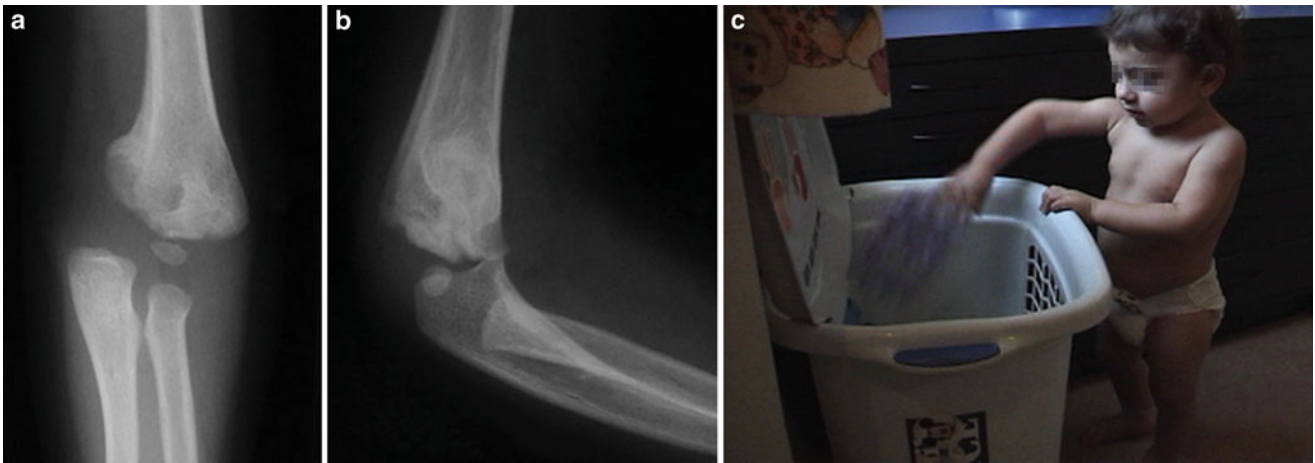
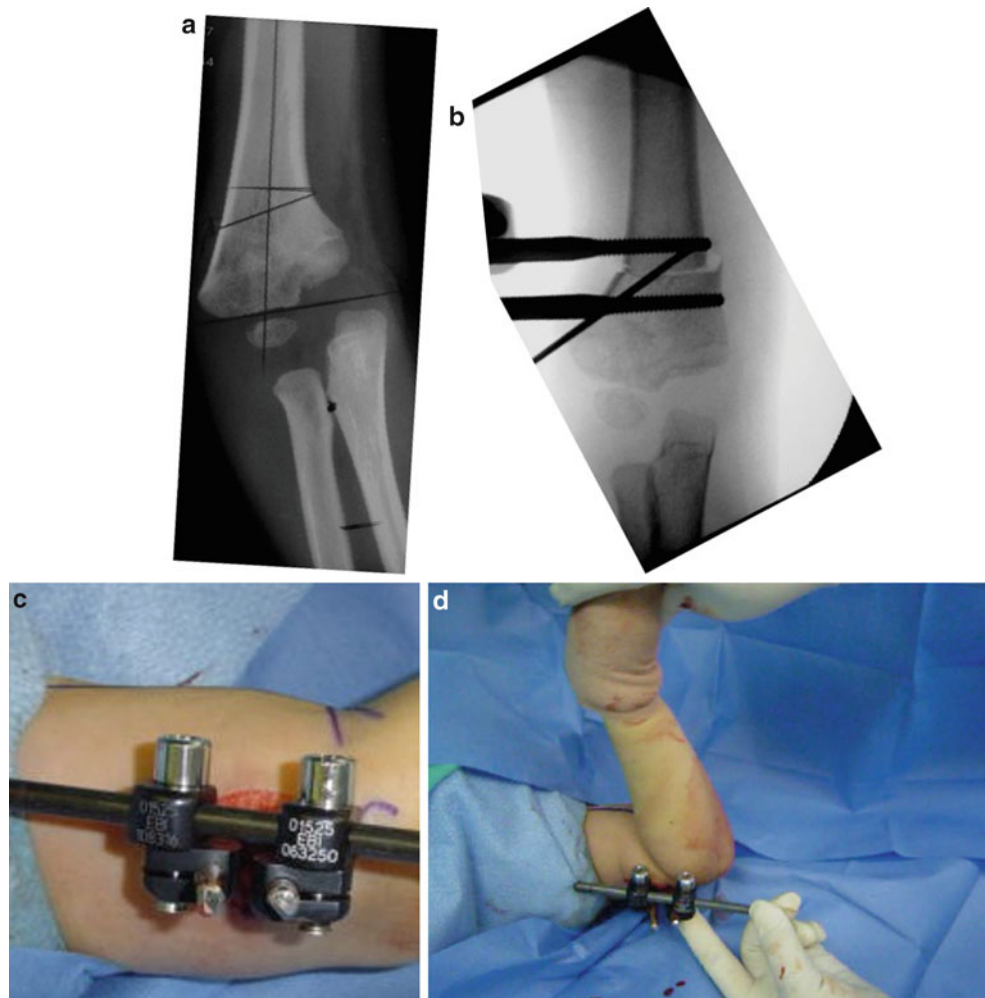


Fig. 3 (a–c) Third AP and LAT X-rays projections and clinical situation

Fig. 4 (a–d) Pre and post Op AP comparative x-rays projections and operative pictures



5 Basic Principles

Other than the recommendations for managing the soft tissues very carefully with a delicate surgical technique, the pre op planning for the right type of osteotomy should also be considered obligatory. Today all the web supported software for image processing have the tools to draw and measure length, axis and angles; so the simulation of different kind of osteotomies is possible.

6 Technical Pearls

It is mandatory to work in a stable situation before you perform a close wedge osteotomy, in order to respect this stability first insert proximal pin perpendicular to the long axis of the diaphysis of the humerus, then the second pin is inserted parallel to the orientation of the distal joint line at the elbow; osteotomies then should be done in a safe metaphyseal zone away from the physis, low energy cuts should be performed following the direction of the previously inserted pins as planned, the classic pre drill with a bit 2.7

or 3.2 with a low revolution power drill is the most acceptable and recommended technique nowadays, then the osteotomies are completed with a proper chisel size proportional to the bone. At this point we already have 2 secure pins that allows to move the distal humerus in a 3-dimensional correction maneuver (angulation, translation and rotation) and then fix the osteotomy with 1 bar and 2 universal clamp simple fixator; advantage is that you can loosen the distal clamp as many times as you need to achieve the correct alignment of the humerus under C arm control and do the final locking of the clamps in the best aligned position, copying the contralateral normal extremity.

At 5 years of age the boy was operated on by means of a lateral closing wedge osteotomy fixed with a simple modular external fixator, 1 carbon bar 2 clamps with 2 screws and a third independent oblique Kirchner wire as a stable osteosynthesis during 8 weeks postoperative. While in the fixator the boy was able to move in flexion extension and pronosupination enough to make normal school activities except for physical education. He then has been followed for 6 more years and he has not developed a new secondary deformity, keeping normal range of movement.

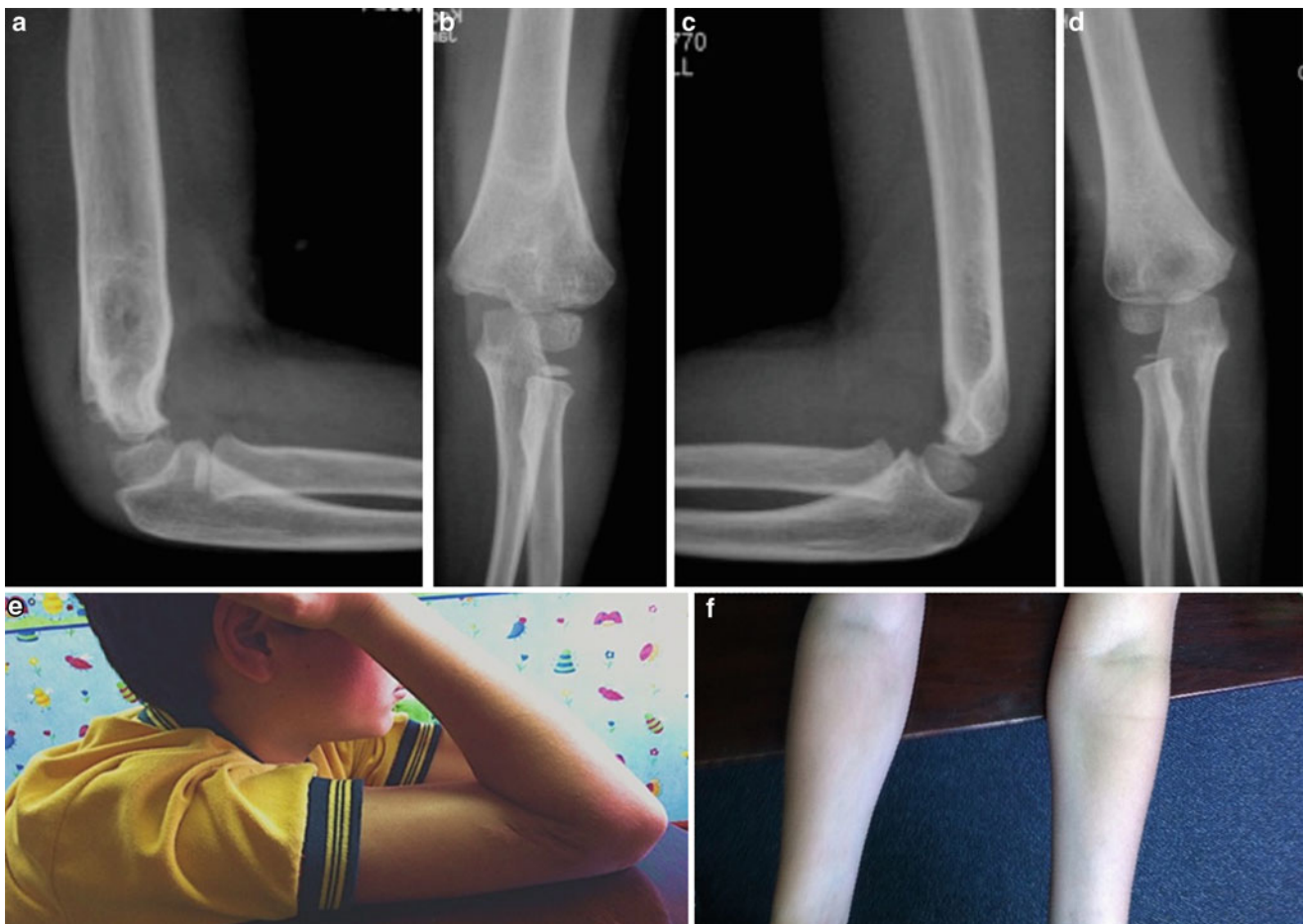


Fig. 5 (a–f) 6 years later follow up x-rays projections and clinical pictures

7 Images During Treatment

See Fig. 4.

8 Outcome Clinical Photos and Radiographs

See Fig. 5.

References and Suggested Readings

Abzug JM, Herman MJ, Kozin SH (2018) Medical fractures of the pediatric elbow I: Supracondylar humerus, lateral condyle. Transphyseal Distal Humerus and Capitellum Fractures 24: e39–e44

Barrett WP, Almquist EA, Staheli LT (1984) Fracture separation of the distal humeral physis in the newborn. *J Pediatr Orthop* 4(5): 617–619

Gilbert SR, Conklin MJ (2007) Presentation of distal humerus physeal separation. *Pediatr Emerg Care* 23(11):816–819

Malik S, Khopkar SR, Korday CS, Jadhav SS, Bhaskar AR (2015) Transphyseal injury of distal humerus: a commonly missed diagnosis in neonates. *J Clin Diagn Res* 9(11):SD01–SD02

Oh CW, Park BC, Ihn JC, Kyung HS (2000) Fracture separation of the distal humeral epiphysis in children younger than three years old. *J Pediatr Orthop* 20(2):173–176

Ratti C, Guindani N, Riva G (2015) Transphyseal elbow fracture in newborn: review of literature. *Musculoskelet Surg*. <https://doi.org/10.1007/s12306-015-0366-z>

Supakul N, Hicks RA, Caltoun CB, Karmazyn B (2015) Distal humeral epiphyseal separation in young children: an often-missed fracture radiographic signs and ultrasound confirmatory diagnosis. *AJR* 204: W192–W198

Oblique Supracondylar Humerus Fracture

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Abstract

Oblique supracondylar humerus fractures represent a subset of supracondylar fractures with additional inherent instability due to their fracture orientation and may present with significant shortening and rotational deformity (Zorrilla et al., *Int Orthop* 39(11):2287–2296, 2015). Closed reduction and percutaneous fixation of closed injuries remains the standard of care, and open reduction is rarely necessary. However, special attention is required to the medial and lateral columns during

reduction and fixation, as well as to the posterior cortex, if there is also a sagittal oblique component to the fracture (Jaeblo et al., *J Pediatr Orthop* 36 (8):787–792, 2016). Depending on the obliquity of the fracture, the lateral-entry pinning technique may need to be modified (Feng et al., *J Pediatr Orthop* 32 (2):196–200, 2012; Wang et al., *J Pediatr Orthop* 21 (6):495–498, 2012). After successful closed reduction, Kirschner wire fixation with 0.062 in or 0.078 in pins in either crossed-pin or lateral-only configuration is acceptable, with the goal of maximizing pin spread at the fracture site and adequate fixation of the medial and lateral columns (Iobst et al., *J Orthop Trauma* 32: e492–e496, 2018; Bahk et al., *J Pediatr Orthop* 28 (5):493–499, 2008). The postoperative course is comparable to transverse supracondylar fractures, with x-rays 1–1.5 weeks postoperatively to ensure maintenance of alignment and pin removal in the office at 3–4 weeks post-op (Reisoglu et al., *Acta Orthop Traumatol Turc* 51 (1):34–38, 2017).

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1 Brief Clinical History

A 7-year-old female who fell onto outstretched left arm on the playground and had immediate pain and swelling, as well as paresthesia's of the hand. She was seen in the Emergency Department where x-rays were taken showing an extension-type supracondylar humerus fracture with 100% displacement, as well as greenstick fractures of distal radius and ulna metaphyses without significant displacement. She was examined by the on-call orthopedic resident, who noted her inability to flex her left index finger DIP or thumb IP joint, consistent with an anterior interosseous nerve (AIN) palsy. She did have palpable radial and ulnar pulses upon presentation. She had exquisite tenderness over her fracture sites, but no injuries elsewhere on secondary examination. Due to her displaced supracondylar humerus fracture with associated nerve palsy, as well as ipsilateral forearm fractures, she was considered at high risk for developing compartment syndrome and was therefore taken to the operating room that evening for fixation. She underwent closed reduction and percutaneous pinning of her oblique supracondylar fracture, followed by closed reduction of her greenstick-type forearm fractures, and healed uneventfully with pins removed at 30 days post-op. She recovered AIN function following surgery.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.



Fig. 1 Images shown are the x-rays of a 7-year-old female who injured her left arm on a playground. She presented to the Emergency Department immediately after the injury. X-rays (**a**, **b**) show a 100% displaced extension-type supracondylar humerus fracture with oblique fracture

3 Preoperative Problem List

Gartland type 3 supracondylar humerus fracture with oblique fracture orientation
Distal radius and ulna metaphyseal greenstick fractures with mild apex volar angulation
AIN palsy
“Floating” elbow due to fractures proximal and distal to elbow joint

4 Treatment Strategy

Supracondylar humerus fractures are extremely common upper extremity injuries in children, and the severity of these injuries is variable (Zorrilla et al. 2015). Due to the fracture location, displacement can result in injury to the neurovascular structures traversing the fracture site, and the incidence of neurovascular injury increases with greater fracture displacement (Zorrilla et al. 2015). Although we normally rely on active patient participation and cooperation to assess neurovascular status, this is often not possible due to young age of the patient, combined with the pain and anxiety associated with injuries that are grossly clinically deformed. For this reason, if a reliable exam is not possible, it is best to proceed with treatment as though there were neurovascular injury present in displaced fractures.

The most useful classification system for extension-type supracondylar humerus fractures is the Gartland classification (Zorrilla et al. 2015). This separates fractures which are non-displaced (type 1), from fractures with intact posterior

orientation, as well as (**c**, **d**) metaphyseal distal radius and ulna greenstick fractures with minimal dorsal displacement. Note the rotational malalignment of the supracondylar humerus fracture (**a**, **b**)

hinge (type 2), and fractures with 100% displacement (type 3). Some have suggested that a fourth type exists, with complete periosteal disruption and buttonhole displacement of the proximal fragment into the antebrachial musculature anteriorly.

Since Gartland type 3 fractures are more likely to be associated with neurovascular injury, they are typically expedited for surgical treatment (Zorrilla et al. 2015). Additionally, “floating” elbow injuries with ipsilateral forearm fractures and supracondylar humerus fracture are considered extremely unstable and warrant more urgent intervention (Blumberg et al. 2018). If the extremity is cold and pulseless distally, this is an urgent indication for surgery, but pink, pulseless extremities can typically be watched closely for several hours before treatment (Zorrilla et al. 2015). Our patient did present with an AIN palsy, pushing us to take her to the operating room that evening.

All supracondylar humerus fractures that are displaced require closed reduction and percutaneous pin fixation, and if a closed reduction is not possible, then open reduction is warranted (Zorrilla et al. 2015). Whether ipsilateral forearm fractures require fixation, as well as reduction, remains controversial, but current thinking is that stable forearm fractures do not require pinning in “floating” elbow injuries (Blumberg et al. 2018).

Plain radiographs are sufficient for preoperative planning. No advanced imaging is necessary. From the preoperative x-rays shown above, it is clear that there is a Gartland type 3 supracondylar humerus fracture with coronal and sagittal plate obliquity, and from this alone, we can anticipate that the fracture will be more unstable to shear forces than a typical type 3 fracture and that this pattern will be more susceptible to extension and rotational malunion (Bahk et al. 2008).

The most important factor in preventing the development of compartment syndrome and subsequent Volkmann contracture with these injuries is to avoid immediate circumferential fiberglass or plaster casts (Blumberg et al. 2018). The decision to treat the forearm fractures versus the supracondylar fracture first is simply surgeon preference.

Closed reduction under fluoroscopic guidance is always attempted first, prior to making an open approach to the fracture. A “milking” maneuver or use of an Esmarch bandage wrapped about the elbow from proximal to distal can be helpful in the initial stage of the closed reduction to establish the correct length of the distal humerus. Next, varus and valgus stress at the fracture site can improve the angulation of the fracture in the frontal plane, as well as direct manual translation of the distal fragment in the medial or lateral direction. Pronation and supination of the forearm can aid in reducing lateral or medial gapping, respectively, and also can improve rotational alignment. The key maneuver in reducing extension-type supracondylar fractures is elbow flexion with direct pressure on the olecranon process while

maintaining the pronated or supinated forearm alignment necessary for rotational stability. Care must be taken not to be too forceful with this flexion maneuver, as an extension-type supracondylar fracture can easily be converted to a flexion-type fracture, which is notoriously more difficult to reduce, especially with an oblique fracture orientation (Bahk et al. 2008).

Assessment of fracture reduction is necessary prior to fixation across the fracture with hardware. The AP view is often difficult to interpret due to superimposition of the proximal radius and ulna on the image, so internal and external oblique x-rays are useful to assess the integrity of the lateral and medial columns, respectively (Zorrilla et al. 2015). The lateral view can be obtained by moving the patient’s arm while maintaining maximum elbow flexion and forearm rotation, or alternatively the c-arm can be manipulated.

The closed reduction is held in place with lateral-entry 0.062 in Kirschner pins. The typical order of pin placement begins with the lateral-most starting point on the capitellum up the lateral column of the distal humerus first, followed by a second pin beginning with a more medial start point and aiming more horizontally toward the medial column. A third pin can be placed between the first two. During pin placement, AP and lateral views are taken to ensure that all pins cross the fracture site, with the goal of maximum spread at the fracture. The choice to use a medial pin is surgeon dependent, with increased risk of ulnar nerve injury but increased biomechanical construct strength with the use of a medial pin. Medial pins can be placed percutaneously with the elbow extended and protection of the ulnar nerve with a thumb holding the nerve posterior to the medial epicondyle or by making a small incision over the medial epicondyle and using a soft tissue protector while placing the pin.

In oblique supracondylar fractures, the use of a 2.0 mm pin or inserting the pin on “oscillate” mode can prevent bounce off the opposite cortex (Iobst et al. 2018). Additionally, a recent biomechanical study demonstrated that for lateral oblique fractures (such as in our patient), three lateral divergent pins provided no benefit over two lateral pins, and the only modality in which two crossed pins was superior to two lateral pins was in valgus stress (Feng et al. 2012).

However, in medial oblique fractures, or “reverse obliquity” fracture patterns, another biomechanical study demonstrated superiority of crossed pins over any lateral pin configuration in all loading conditions (Wang et al. 2012). If our fracture had been a reverse obliquity pattern, placement of lateral-entry pins may have been difficult, and medial-entry pins would have been favored.

The vascular status of the extremity is always assessed prior to completion of the procedure. If pulses are neither

palpable nor dopplerable, this is an indication to remove the pins and explore the brachial artery (Zorrilla et al. 2015).

After closed reduction of the minimally displaced forearm fractures, long-arm cast placement is acceptable if the cast is bivalved to accommodate swelling (Blumberg et al. 2018). A noncircumferential posterior long-arm splint would also be an acceptable mode of immobilization for the 1st week after surgery (Blumberg et al. 2018).

Postoperatively, patients require close monitoring for frequent neurovascular checks to avoid the dreaded complication of compartment syndrome (Zorrilla et al. 2015). Patients are typically kept inpatient for 24 h for more severe-type injuries, especially if a preoperative neurapraxia is present.

Patients are seen 1–1.5 weeks after surgery for x-rays to determine if alignment has maintained and then at 3–4 weeks postoperatively for pin removal in the office (Zorrilla et al. 2015; Reisoglu et al. 2017). At that time, a determination is made based on x-ray healing and clinical tenderness over the fracture site whether an additional period of casting is needed. The risk of prolonged immobilization is elbow stiffness (Zorrilla et al. 2015).

- Pronation/supination to correct gapping laterally or medially, respectively, or rotational alignment
- Flexion with thumb on olecranon process while holding pronosupination
- Checking AP, lateral, and medial and lateral oblique views for column assessment
- Convert to open reduction if unable to achieve adequate reduction closed

Fixation:

- Use 0.062 in or 0.078 in Kirschner pins, 0.054 in only in very small children.
- Larger pin or insertion on “oscillate” mode to prevent bounce off opposite cortex.
- Maximize distance between pins at fracture.
- Lateral-entry pins first, begin with lateral column pin.
- For medial oblique fracture, medial-entry pins provide more stability than lateral-entry pins.
- For lateral oblique fracture, lateral-entry pins provide more stability than medial-entry pins.
- Two crossed pins are always a stable configuration.
- Risk of ulnar nerve injury or stretch over medial pin.

5 Basic Principles

Closed Reduction:

- Longitudinal traction at 20–30° of elbow flexion
- Esmarch proximal to distal, “milking maneuver” to establish fracture length
- Varus/valgus force to correct angulation
- Manual translation of distal fragment

6 Images During Treatment

AP and lateral views are necessary for assessment of reduction and pin placement, but medial and lateral oblique views are helpful in visualizing the lateral and medial columns, respectively. These views are especially helpful prior to pin fixation when the elbow cannot be extended for a true AP view (Fig. 2).

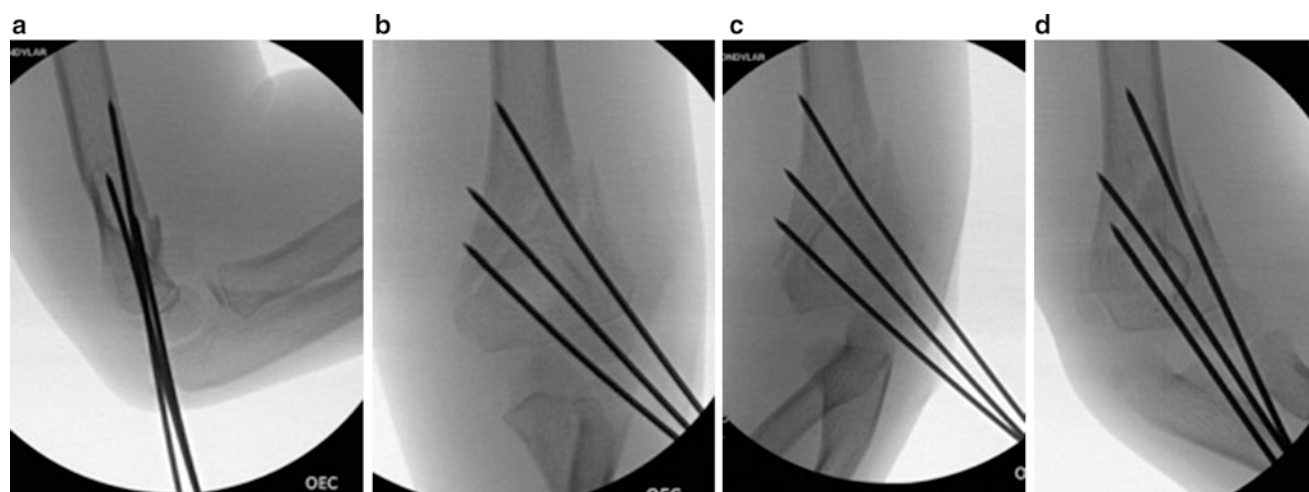


Fig. 2 X-rays of left Gartland type 3 supracondylar humerus fracture with lateral coronal oblique fracture orientation reduced and stabilized with three lateral-entry 0.062 in pins (a–d)

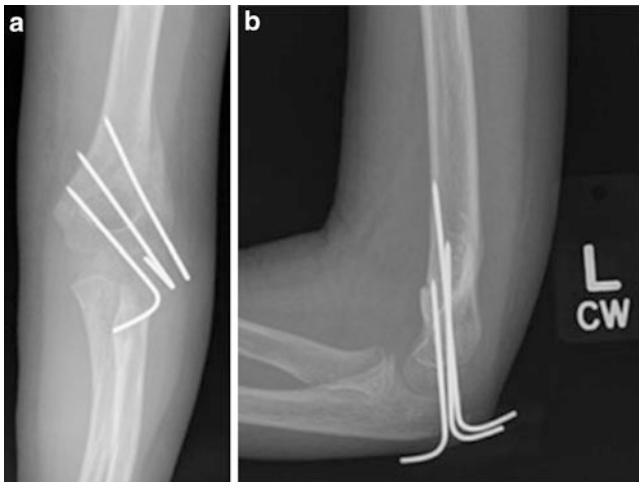


Fig. 3 A 7-year-old female 30 days' status post closed reduction and percutaneous fixation of coronal lateral oblique supracondylar humerus fracture. Note the lateral periosteal new bone formation at the apex of the fracture on the AP view (a) and maintenance of the anterior humeral line on the lateral view (b). Her ipsilateral greenstick forearm fractures healed uneventfully with closed reduction

7 Technical Pearls

- Correct sequence of reduction maneuvers, with flexion last
- Lateral pins first
- Maximum angle to prevent wire “bounce” off opposite cortex 68° (0.062) or 74° (0.078)
- Extension of the elbow for placement of medial pin, if needed
- Recognition of especially unstable fracture patterns

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

Achieving and maintaining anatomic reduction is the most challenging aspect of treating oblique supracondylar humerus fractures due to their inherent instability to shear forces (Reisoglu et al. 2017). Medial comminution can also lead to varus collapse (Zorrilla et al. 2015; Reisoglu et al. 2017). Ensuring adequate alignment prior to percutaneous pin fixation is critical. If near-anatomic alignment cannot be achieved with closed reduction, an open approach may be used for

direct reduction, but this is rarely necessary (Zorrilla et al. 2015). X-rays should be taken at 1–1.5 weeks postoperatively to determine if alignment has been maintained or lost (Reisoglu et al. 2017). At this time, if needed, the patient can be taken back to surgery for revision reduction and fixation without the need for osteotomy. Pin site infections are rare, but are typically managed with oral antibiotics and removal of the pin, if loose (Zorrilla et al. 2015).

10 Cross-References

- ▶ [Open Treatment of Supracondylar Humerus Fractures](#)
- ▶ [Supracondylar Humerus Fracture Extension Type: Cross Pinning](#)
- ▶ [Supracondylar Humerus Fracture Extension Type: Lateral Entry Pinning](#)
- ▶ [Supracondylar Humerus Fracture Flexion Type](#)
- ▶ [Supracondylar Femur Fracture: Treatment with a Submuscular Plate](#)
- ▶ [Treatment of a Pediatric Open Supracondylar Femur Fracture with External Fixation](#)
- ▶ [Type III Supracondylar Humerus Fracture](#)

References

- Bahk MS, Srikumaran U, Ain MC, Erkula G, Leet AI, Sangent MC, Spondseller PD (2008) Patterns of pediatric supracondylar humerus fractures. *J Pediatr Orthop* 28(5):493–499
- Blumberg TJ, Bremjit P, Bompadre V, Steinman S (2018) Forearm fixation is not necessary in the treatment of pediatric floating elbow. *J Pediatr Orthop* 38(2):82–87
- Feng C, Guo Y, Zhu Z, Zhang J, Wang Y (2012) Biomechanical analysis of supracondylar humerus fracture pinning for fractures with coronal lateral obliquity. *J Pediatr Orthop* 32(2):196–200
- Iobst C, Thompson RG, Grauer J, Wheeler P (2018) How to prevent k-wire bounce in oblique supracondylar humerus fractures. *J Orthop Trauma* 32:e492–e496. Epub ahead of print
- Jaebon T, Anthony S, Ogden A, Andary JJ (2016) Pediatric supracondylar fractures: variation in fracture patterns and the biomechanical effects of pin configuration. *J Pediatr Orthop* 36(8):787–792
- Reisoglu A, Kazimoglu C, Hanay E, Agus H (2017) Is pin configuration the only factor causing loss of reduction in the management of pediatric type III supracondylar fractures? *Acta Orthop Traumatol Turc* 51(1):34–38
- Wang X, Feng C, Wan S, Bian Z, Zhang J, Song M, Shao J, Yang X (2012) Biomechanical analysis of pinning configurations for a supracondylar humerus fracture with coronal medial obliquity. *J Pediatr Orthop* 21(6):495–498
- Zorrilla S, de Neira J, Prada-Canizares A, Marti-Ciruelos R, Pretell-Mazzini J (2015) Supracondylar humeral fractures in children: current concepts for management and prognosis. *Int Orthop* 39(11):2287–2296

Minimally Displaced Lateral Condyle Fractures of the Elbow: Treatment with Arthrography and Percutaneous Cannulated Screw Fixation

Kevin M. Neal

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Abstract

Lateral condyle fractures of the elbow in children are relatively common. Typically classified as Salter-Harris IV injuries, they cross the distal humeral physis and may enter the elbow joint through the trochlea. When displaced, they must be anatomically reduced to avoid malalignment and minimize the potential for posttraumatic arthritis at the joint surface. When nondisplaced, they are amenable to conservative management, typically with a long arm cast. Fractures with indeterminate displacement can be assessed either by using an MRI scan or arthrography. An assessment in the operating room using an elbow arthrogram also allows percutaneous fixation to be completed in the same setting. This chapter discussed the indications for elbow arthrography and percutaneous fixation of minimally displaced lateral condyle fractures, as well as the risks and

benefits of fixation using cannulated screws versus percutaneous pins, and the typical postoperative management when using percutaneous cannulated screws.

A 9-year-old boy fell while riding his bike and injured his left arm. He had immediate pain, swelling at the elbow, and difficulty moving the arm. Radiographs in the emergency department revealed a minimally displaced lateral condyle fracture. He was splinted and scheduled for assessment in the operating room with an elbow arthrogram and possible internal fixation. After a discussion of options with the family, the patient was given a general anesthetic, and a left elbow arthrogram was performed. The arthrogram revealed an intact cartilaginous joint surface, and percutaneous fixation was performed using a 4.0 mm cannulated screw. Postoperatively, the patient was maintained in a long arm cast for 6 weeks, followed by physical therapy to regain range of motion and strength for another 6 weeks. The patient healed the lateral condyle fracture well, and the cannulated screw was removed under a second anesthetic as an outpatient procedure about 6 months later.

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1 Brief Clinical History

A 9-year-old boy injured his left elbow after a fall from his bicycle. He had immediate pain, swelling, deformity, and the inability to move the left elbow. Evaluation in the emergency department revealed a minimally displaced lateral condyle fracture (Fig. 1), with intact motor and sensory function in the left hand, as well as a normal radial pulse, and normal capillary refill. A long arm posterior splint was applied, and the patient was scheduled for evaluation in the operating room with an elbow arthrogram and possible percutaneous fixation.

2 Preoperative Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Minimally displaced lateral condyle fracture of the left elbow

4 Treatment Strategy

There are several different classifications available to describe pediatric lateral condyle fractures. The most relevant classifications use some version of nondisplaced, minimally displaced, or completely displaced categories. For minimally displaced fractures, controversy exists regarding acceptable amounts of displacement and the most appropriate treatment algorithms. In the age group that sustains lateral condyle fractures, the distal humerus remains mostly cartilaginous, making assessment of the amount of displacement at this

location difficult. The most important consideration when assessing these injuries is to determine whether the distal humeral joint surface remains intact or whether it has been displaced by the fracture. If the joint surface has been displaced, consideration should be given to open reduction and internal fixation to ensure anatomic alignment of the trochlea. If the joint surface has not been displaced, open reduction should not be required. When the joint surface is not displaced, consideration can still be given to percutaneous fixation of the fracture to ensure stability and limit any potential for late displacement. Methods of fixation are somewhat controversial, with a common method utilizing multiple percutaneous K-wires. However, our preferred method is percutaneous fixation using a cannulated lag screw. The benefits of using screw fixation instead of percutaneous K-wires may include improved stability of the fracture fixation, a decreased rate of delayed union or nonunion, elimination of any chance of pin tract cellulitis, and a decreased incidence of lateral bony overgrowth leading to a visible lateral prominence. Disadvantages of screw fixation might include the need for a second anesthetic for implant removal and the cost associated with a more expensive choice of implant.

5 Basic Principles

1. Under sterile conditions, a 50-50 mixture of contrast media and saline is injected into the elbow under fluoroscopic guidance. Adequate arthrograms can be obtained using several different approaches, with the posterolateral “soft spot” of the elbow, and the posterior olecranon fossa being popular choices.
2. Fluoroscopy is used to confirm an adequate arthrogram. The elbow is evaluated using intermittent and live fluoroscopy to visualize the distal humeral joint surface, and

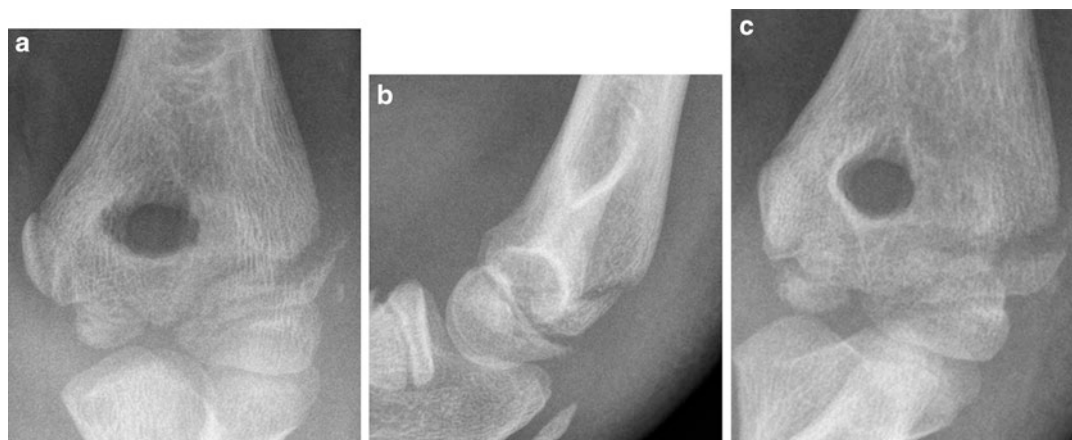


Fig. 1 AP (a) lateral (b) and oblique (c) views of the left elbow, demonstrating a minimally displaced lateral condyle fracture

determine whether there is any significant displacement (Fig. 2).

3. Significant displacement requires an open approach to the elbow, utilizing an oblique lateral incision and the traditional Kocher technique. (Open treatment is discussed in chapter ► [“Displaced Elbow Lateral Condyle Fracture: Treatment with a Cannulated Screw”](#))
4. If the joint surface is nondisplaced or minimally displaced, the fracture is amenable to percutaneous fixation to improve fracture stability and avoid any late displacement.
5. A small incision, only large enough to accommodate a screw head, is made using a scalpel at the distal, lateral aspect of the humerus.
6. A percutaneous guidewire is placed through this incision and driven up the lateral column of the humerus, across the fracture site, and through the far cortex.
7. Adequate positioning of the guidewire is checked on multiplane fluoroscopy.
8. The guidewire is overreamed, and a 4.0 mm partially threaded cannulated screw is placed across the fracture in a lagged fashion.
9. Fluoroscopy and direct visualization of the fracture site are used to confirm an adequate reduction with good position of the implant (Fig. 3).
10. The wound is closed with absorbable suture and a well-padded long arm cast is placed.
11. The cast is maintained for about 6 weeks.
12. The cast is then removed, radiographs are taken to confirm adequate healing, and therapy is initiated for range of motion of the elbow.
13. A return to normal activity is typically allowed at about 12 weeks following surgery, when the fracture has healed, and the patient has regained acceptable range of motion and strength (Fig. 3).

Fig. 2 AP (a) and oblique (b) views of the left elbow, showing a left elbow arthrogram, used to visualize the distal joint surface with a lateral condyle fracture. No displacement of the joint surface is noted

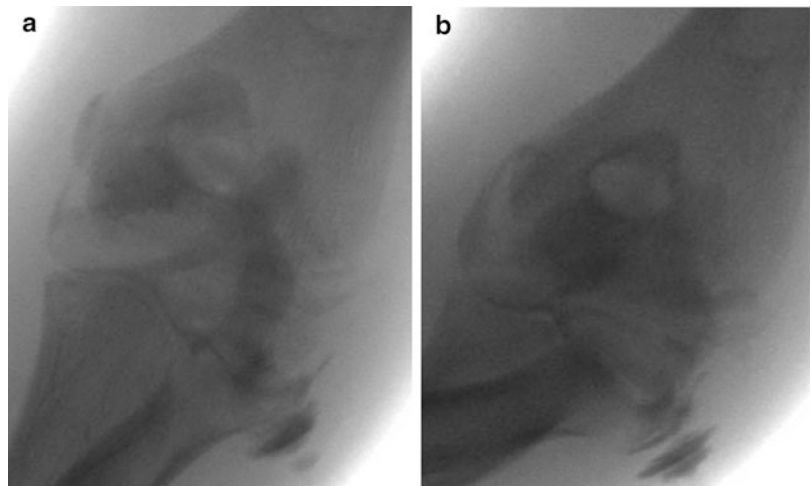


Fig. 3 AP (a) and lateral (b) views of the left elbow, showing fixation across the lateral condyle of the distal humerus with a 4.0 mm partially threaded screw

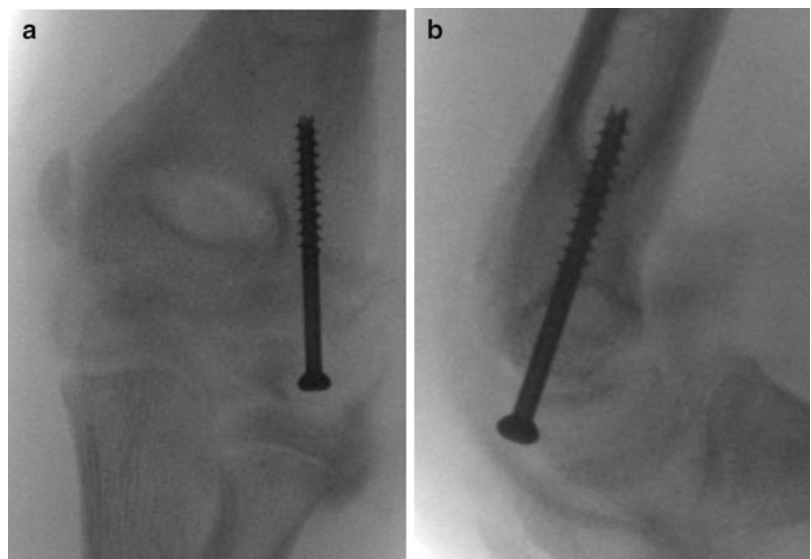
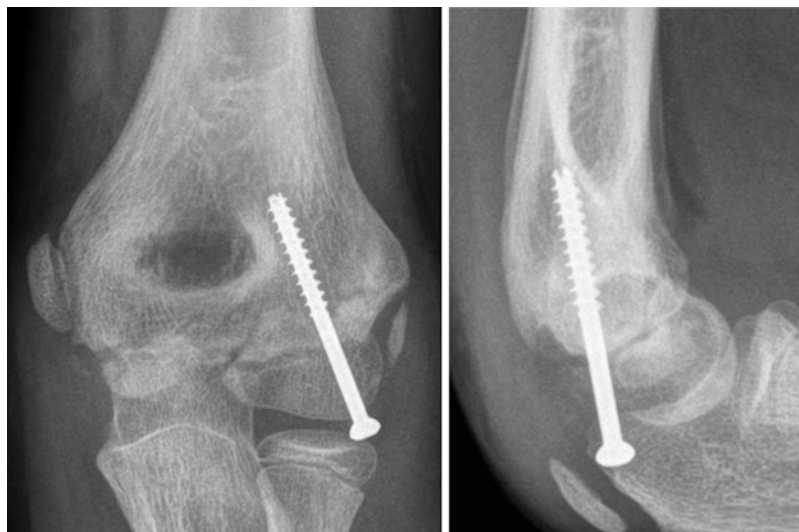


Fig. 4 AP (a) and lateral (b) views of the left elbow, 3 months after an arthrogram and percutaneous fixation, showing adequate healing and alignment



14. The incidence of a clinically significant physeal arrest is low with lateral condyle fractures, due to the paucity of longitudinal growth at the distal humerus. However, screw removal can be performed at 6 to 12 months following the original injury to avoid leaving a potential tether across the distal humeral physis.

6 Images During Treatment

See Figs. 2 and 3.

7 Technical Pearls

1. Injection of arthrographic dye under live fluoroscopy can confirm adequate position within the elbow joint. If the injected dye appears to be outside of the joint, the needle can be quickly repositioned.
2. The distal humerus frequently has poor or absent cancellous bone. If needed, lag fixation can be achieved by including purchase of the posterior or medial cortex of the distal humerus.
3. A significant portion of the lateral condyle remains cartilaginous in the age groups most likely to sustain lateral condyle fractures. When planning the length of the screw, allow for some plowing of the screw head through soft cartilage before it engages the more robust calcified lateral condyle. A washer can be used for improved purchase of the proximal screw in the cartilage.
4. When reaming over the guide wire, the guidewire may lose purchase and be removed when the reamer is withdrawn. Be prepared to replace the guidewire back

into the same position, using adjunctive fluoroscopy if needed.

8 Outcome Clinical Photos and Radiographs

See Fig. 4.

9 Avoiding and Managing Problems

1. Due to the intraarticular nature of the lateral condyle fracture, bony healing may be delayed compared to other injuries in children, because the fracture may be constantly infiltrated by synovial fluid from the elbow joint.
2. Full range of motion may not be regained for up to a year following the injury, though functional range of motion is typically regained much sooner.
3. The distal humerus grows very slowly compared to the proximal humerus. Therefore, incidences of physeal arrest are extremely rare at this location. To avoid any potential for angular deformity related to physeal arrest, we recommend routine removal of the implant between 6 and 12 months after the original surgery.

10 Cross-References

- [An Elbow Dislocation with and Without Additional Fractures](#)
- [Displaced Elbow Lateral Condyle Fracture: Treatment with a Cannulated Screw](#)
- [Medial Condyle Fracture](#)
- [Medial Epicondyle Fractures](#)

References and Suggested Readings

- Li WC, Xu RJ (2012) Comparison of Kirschner wires and AO cannulated screw internal fixation for displaced lateral humeral condyle fracture in children. *Int Orthop* 36(6):1261–1266
- Marzo JM, d'Amato C, Strong M, Gillespie R (1990) Usefulness and accuracy of arthrography in management of lateral humeral condyle fractures in children. *J Pediatr Orthop* 10(3):317–321
- Schlitz RS, Schwertz JM, Eberhardt AW, Gilbert SR (2015) Biomechanical analysis of screws versus K-wires for lateral humeral condyle fractures. *J Pediatr Orthop* 35(8):e93–e97
- Sharma JC, Arora A, Mathur NC, Gupta SP, Biyani A, Mathur R (1995) Lateral condylar fractures of the humerus in children: fixation with partially threaded 4.0-mm AO cancellous screws. *J Trauma* 39(6):1129–1133
- Shirley E, Anderson M, Neal K, Mazur J (2015) Screw fixation of lateral condyle fractures: results of treatment. *J Pediatr Orthop* 35(8):821–824
- Weiss JM, Graves S, Yang S, Mendelsohn E, Kay RM, Skaggs DL (2009) A new classification system predictive of complications in surgically treated pediatric humeral lateral condyle fractures. *J Pediatr Orthop* 29(6):602–605

Displaced Elbow Lateral Condyle Fracture: Treatment with a Cannulated Screw

Kevin M. Neal

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Abstract

Lateral condyle fractures of the elbow in children are relatively common. Typically classified as Salter-Harris IV injuries, they cross the distal humeral physis and may enter the elbow joint through the trochlea. When displaced, they must be anatomically reduced to avoid malalignment and minimize the potential for post-traumatic arthritis at the joint surface. This chapter discussed the indications for operative management of displaced lateral condyle fractures, the risks and benefits of fixation using cannulated screws versus percutaneous pins, and the typical postoperative management when using cannulated screws.

A 7-year-old boy fell from a jungle gym at school and injured his left arm. He had immediate pain, swelling at the elbow, and difficulty moving the arm. Radiographs in the emergency department revealed a displaced lateral

condyle fracture. He was splinted and scheduled for open reduction with internal fixation. After a discussion of options with the family, the patient was given a general anesthetic, and an open reduction with internal fixation utilizing a 4.0 mm cannulated screw was performed. Postoperatively, the patient was maintained in a long arm cast for 6 weeks, followed by physical therapy to regain range of motion and strength for another 6 weeks. The patient healed the lateral condyle fracture well, and the cannulated screw was removed under a second anesthetic as an outpatient procedure about 6 months later.

1 Brief Clinical History

A 7-year-old boy injured his left elbow after a fall off playground equipment. He had immediate pain, swelling, deformity, and the inability to move the elbow. Evaluation in the emergency department revealed a displaced lateral condyle fracture (Fig. 1), with intact motor and sensory function in the left arm, as well as a normal radial pulse, and normal capillary

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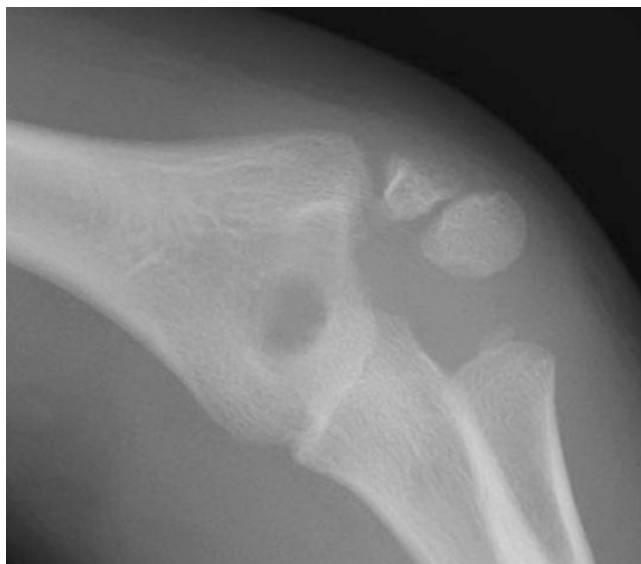


Fig. 1 AP view of the left elbow, demonstrating a displaced lateral condyle fracture

refill. A long arm posterior splint was applied, and the patient was scheduled for operative fixation of the lateral condyle fracture.

1.1 Preoperative Radiographs, Following Closed Manipulation

See Fig. 1.

1.2 Preoperative Problem List

1. Displaced lateral condyle fracture of the left elbow

2 Treatment Strategy

There are several different classifications available to describe pediatric lateral condyle fractures. The most relevant are those which classify the injuries as some version of nondisplaced, minimally displaced, or completely displaced. Nondisplaced fractures are usually amenable to nonoperative management. Minimally displaced fractures may be amenable to percutaneous fixation. Percutaneous reduction of displaced lateral condyle fractures may not restore adequate, near-anatomic alignment of the joint surface of the distal humerus. For completely displaced fractures, open reduction with fixation of the displaced fragment is recommended to restore the normal anatomy

of the distal humeral surface. Methods of fixation are somewhat controversial, with the most common method being multiple K-wires, either left percutaneously or buried beneath the skin. Our preferred method is internal fixation using a cannulated lag screw. The benefits of using screw fixation instead of percutaneous K-wires may include improved stability of the fracture fixation, a decreased rate of delayed union or nonunion, elimination of any chance of pin tract cellulitis, and a decreased incidence of lateral bony overgrowth leading to a visible lateral prominence. Disadvantages of screw fixation include the need for a second anesthetic for implant removal, and the cost associated with a more expensive choice of implant.

3 Basic Principles

1. A lateral approach to the elbow joint, utilizing an oblique lateral incision and the traditional Kocher technique is performed.
2. The anterior trochlea is directly visualized, and an anatomic reduction is performed.
3. A guidewire is driven up the lateral column of the humerus, across the fracture site, and through the far cortex in the humeral metaphysis.
4. Adequate positioning of the guidewire is checked on multiplane fluoroscopy.
5. The guidewire is over-drilled, and a 4.0 mm partially threaded cannulated screw is placed across the fracture in a lagged fashion.
6. Fluoroscopy and direct visualization of the fracture site are used to confirm an adequate reduction with good position of the implant (Fig. 2).
7. The wound is closed with absorbable suture and a well-padded long arm cast is placed.
8. The cast is maintained for about 6 weeks.
9. The cast is then removed, radiographs are taken to confirm adequate healing, and therapy is initiated for range of motion of the elbow.
10. A return to normal activity is typically allowed at about 12 weeks following surgery, when the fracture has healed, and the patient has regained acceptable range of motion and strength (Fig. 3).
11. The incidence of a clinically significant physeal arrest is low with lateral condyle fractures, due to the paucity of longitudinal growth at the distal humerus. However, screw removal can be performed at 6–12 months following the original injury to avoid leaving a potential tether across the distal humeral physis.

4 Images During Treatment

See Fig. 2.

5 Technical Pearls

1. During a lateral approach to a lateral condyle fracture, the intermuscular interval is frequently defined by the large fracture hematoma, making the approach path relatively obvious.
2. The mobile wad origin at the lateral condyle may make visualization of the reduction difficult. A small portion of the mobile wad can be released at its origin using electrocautery, and retracted posteriorly to improve visualization of the joint.
3. A right angled retractor placed across the anterior elbow joint aids visualization of the entire trochlea.
4. A small dental mirror placed into the anterior elbow may aid visualization of the fracture, though adequate lighting is required.
5. The distal humerus frequently has poor or absent cancellous bone, so we recommend using a lag technique, including purchase of the medial cortex of the distal humerus.
6. On a true lateral radiograph, the lateral condyle is slightly anterior, and the medial epicondyle is slightly posterior. To achieve adequate purchase in the lateral condylar fragment, the guide pin and screw trajectory should be from distal-anterior to proximal-posterior on the lateral image (Fig. 2c).
7. A significant portion of the lateral condyle remains cartilaginous in the age groups most likely to sustain lateral condyle fractures. When planning the length of the screw,

Fig. 2 AP (a), oblique (b), and lateral (c) views of the left elbow, showing a lateral condyle fracture fixed using a 4.0 mm cannulated screw. A near-anatomic reduction has been achieved

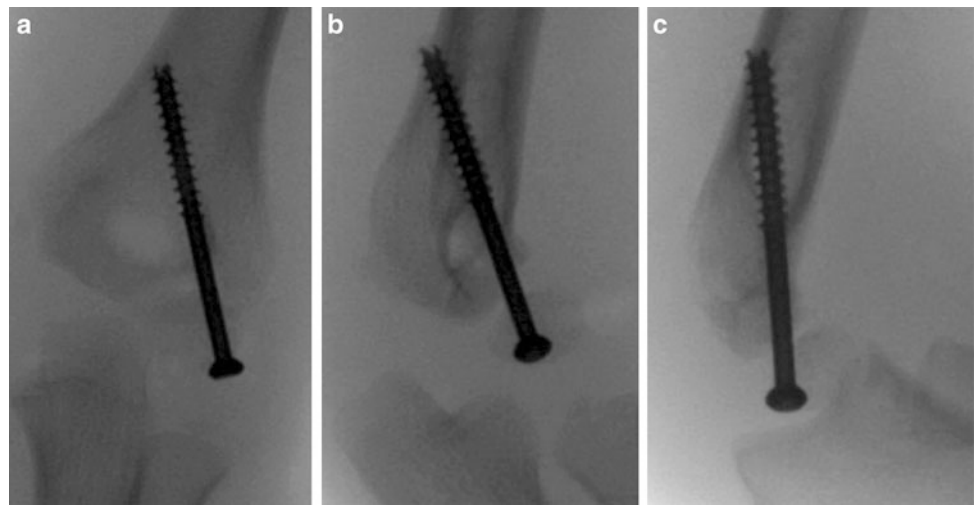
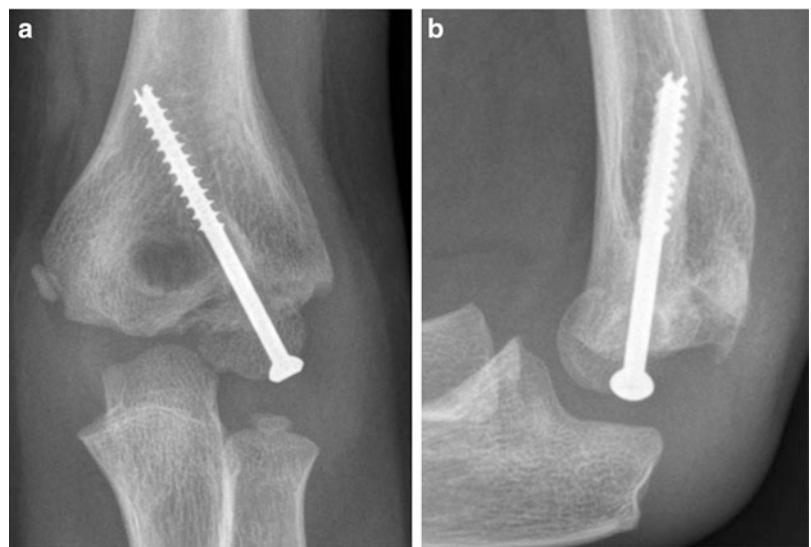


Fig. 3 AP (a) and lateral (b) views of the left elbow, 3 months after open reduction and internal fixation, showing adequate healing and alignment



allow for some plowing of the screw head through soft cartilage before it engages the more robust calcified lateral condyle. A washer can be used for improved purchase of the proximal screw in the cartilage.

8. When reaming through the far cortex of the distal humerus over the guide wire, the guidewire may lose purchase and be removed when the reamer is withdrawn. Be prepared to maintain the reduction with other methods, such as a dental pick, and to replace the guidewire immediately.
9. When placing the screw over the guidewire, use a backup method, such as a dental pick, to avoid rotation of the fracture fragment.

6 Outcome Clinical Photos and Radiographs

See Fig. 3.

7 Avoiding and Managing Problems

1. Due to the intra-articular nature of the lateral condyle fracture, bony healing may be delayed compared to other injuries in children, because the fracture may be constantly infiltrated by synovial fluid from the elbow joint.
2. Full range of motion may not be regained for up to a year following lateral condyle fractures, though functional range of motion is typically regained much sooner.
3. The distal humerus grows very slowly compared to the proximal humerus. Therefore, incidences of clinically relevant physeal arrest are extremely rare at this location. To

avoid any potential for angular deformity related to physeal arrest, we recommend routine removal of the implant between 6 and 12 months after the original surgery.

8 Cross-References

- [An Elbow Dislocation with and Without Additional Fractures](#)
- [Medial Condyle Fracture](#)
- [Medial Epicondyle Fractures](#)
- [Minimally Displaced Lateral Condyle Fractures of the Elbow: Treatment with Arthrography and Percutaneous Cannulated Screw Fixation](#)

References and Suggested Reading

- Li WC, Xu RJ (2012) Comparison of Kirschner wires and AO cannulated screw internal fixation for displaced lateral humeral condyle fracture in children. *Int Orthop* 36(6):1261–1266
- Schlitz RS, Schwartz JM, Eberhardt AW, Gilbert SR (2015) Biomechanical analysis of screws versus K-wires for lateral humeral condyle fractures. *J Pediatr Orthop* 35(8):e93–e97
- Sharma JC, Arora A, Mathur NC, Gupta SP, Biyani A, Mathur R (1995) Lateral condylar fractures of the humerus in children: fixation with partially threaded 4.0-mm AO cancellous screws. *J Trauma* 39(6):1129–1133
- Shirley E, Anderson M, Neal K, Mazur J (2015) Screw fixation of lateral condyle fractures: results of treatment. *J Pediatr Orthop* 35(8):821–824
- Weiss JM, Graves S, Yang S, Mendelsohn E, Kay RM, Skaggs DL (2009) A new classification system predictive of complications in surgically treated pediatric humeral lateral condyle fractures. *J Pediatr Orthop* 29(6):602–605

Capitellar Fractures

Jamil Faissal Soni, Weverley Rubele Valenza, and
Armando Romani Secundino

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Abstract

Fracture of the capitellum is rare accounting for 1% of elbow injuries. It involves patients from 12 years of age and older. The most common mechanism is fall on an outstretched hand that results in an axial compressive force that is transmitted to the capitellum by the radial head. This mechanism of trauma causes fracture in the coronal plane of the humeral capitellum. In fact, Bryan and Morrey (Fig. 3) drafted the most popular classification of capitellar fractures: type I (Hans-Steinthal) coronal shear fracture resulting in an osteochondral fragment, type II (Kocher-Lorenz) coronal shear fracture resulting a cartilaginous fragment, type III multifragmentary fracture, and type IV (McKee

modification type) coronal shear fracture that includes the capitellum and trochlea. The treatment is mostly surgical, with a wide variety of access options. Some of them include lateral, extended lateral, anterolateral, and posterior. We do consider extended lateral as being the best choice, because it provides the most accurate angle to ensure anatomic reduction and stable internal fixation. The fixation must be stable enough to encourage early mobility and prevent eventual complications, such as elbow contracture, nonunion, and arthrosis.

1 Brief Clinical History

A male, 15 years old, right-handed, fell from a bike, with an outstretched hand. Physical exam showed moderated pain, edema, and functional limitation on the left elbow. His hand was pink, presenting radial pulse and had no neurological disturbance. There was no evidence of other musculoskeletal or systemic injuries.

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Fig. 1 Anteroposterior (AP) X-ray showing a fracture. Capitellum from type I (Hans-Steinthal)



Fig. 2 Lateral X-ray showing fragment displacement superiorly

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4.

3 Preoperative Problem List

- Recognition of fracture and displacement
- Planning of surgical approach
- Restore joint congruence
- Fixation method
- Gain postoperative motion

4 Treatment Strategy

Patients underwent surgery with general and regional anesthesia in the supine position on a radiolucent arm table and using a sterile pneumatic tourniquet. We recommend the extended lateral approach, centered on the lateral epicondyle, with the proximal extension directed to the lateral column of the humerus and the distal extension 2 cm to the radial head. The forearm is pronated, and the interval is located between the anconeus muscle and the

extensor carpi ulnaris muscle (Kocher interval); in the proximal aspect of the muscular interval, a subperiosteal flap of the capsule with the wrist extensors is made. The release of the ulnar collateral ligament and the dissection of the posterior muscles of the humerus must be avoided. This approach gives an excellent view of the fracture, allowing better reduction and congruence of the articular surface. Temporary fixation is made with guide wires or with Kirschner wires. The fracture reduction has to be checked on image intensifier, and in the presence of anatomic reduction, fixation is carried out with the headless double-threaded compression screws from anterior to posterior. It is recommended to close the Kocher interval and insertion of the extensor muscles. Postoperative immobilization, using plaster splint for about 7 days, is recommended. Active and passive range of motion of the elbow is initiated after this period of time (Ruchelsman et al. 2008).

5 Basic Principles

- Wide access allowing visualization of the fracture and appropriate reduction.

Fig. 3 Bryan-Morrey classification, modified by McKee (Bryan RS and Morrey BF 1985; McKee et al. 1996)

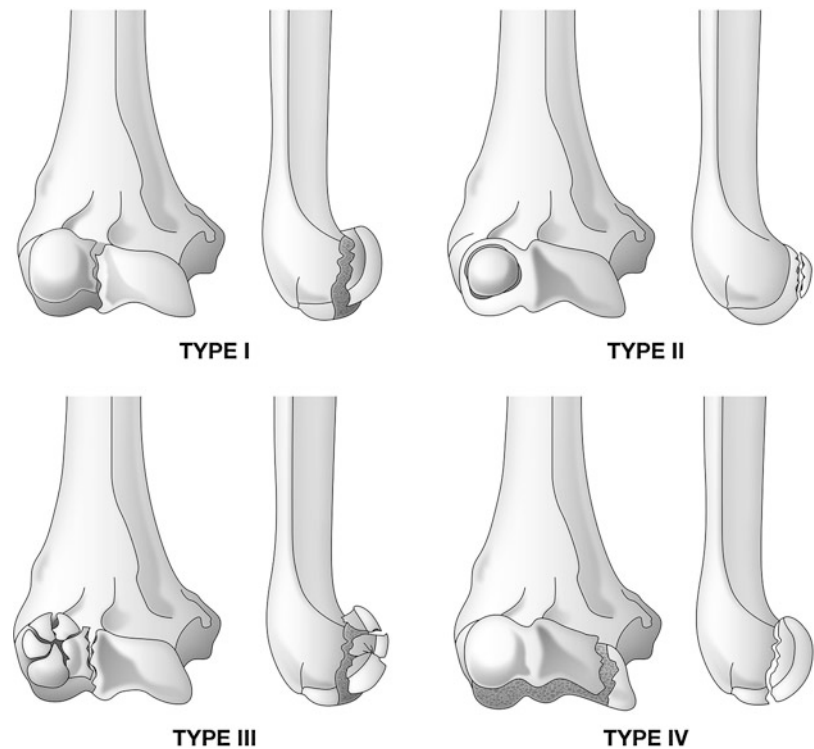


Fig. 4 Computed tomography (CT) is useful for displacement analysis and treatment decision

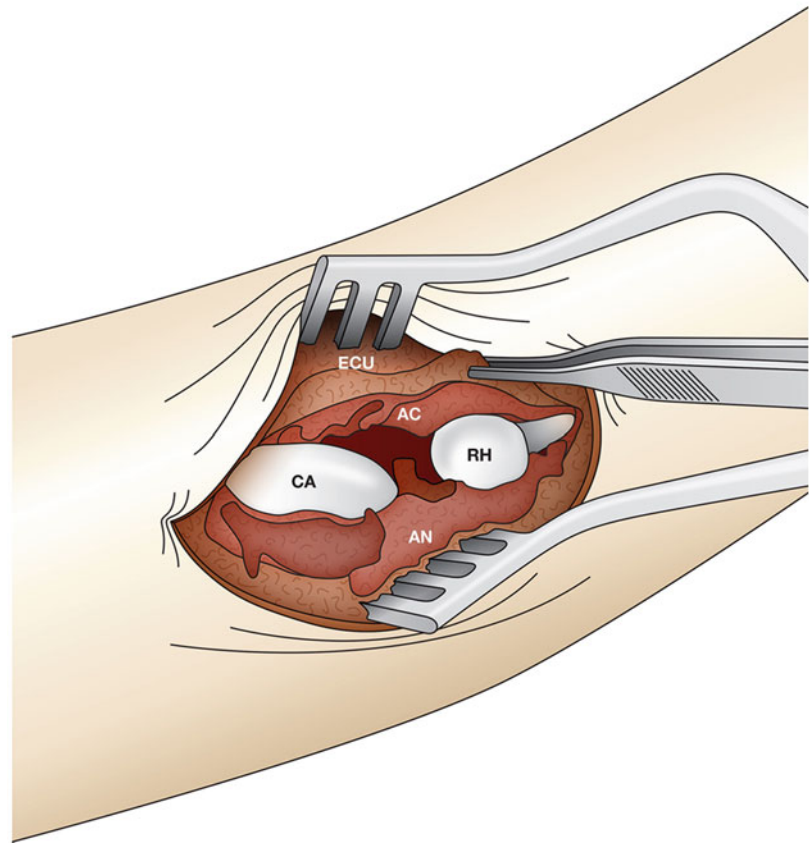
- Pronated forearm to avoid injury to the posterior interosseous nerve and the detachment of the ulnar collateral ligament, reducing the odds of elbow instability.



Fig. 5 Extended lateral incision, centered on the lateral epicondyle of about 12 cm

- Do not dissect the posterior portion of the capitellum; detachment of the muscles may cause avascular necrosis.
- Obtaining anatomic reduction with restoration of joint congruity and stable fixation prevents posttraumatic arthrosis.
- It must be stable enough to allow early mobility and prevent elbow stiffness (Vaishya et al. 2016; Trinh et al. 2012; Letts et al. 1997).

Fig. 6 A drawing that shows the radial head (*RH*); the capitellum (*CA*); the subperiosteal flap, closes to the anterior capsule (*AC*); the ulnar extensor of the wrist muscle (*ECU*); and the Kocher distal interval



6 Images During Treatment

See Figs. 5, 6, and 7.

7 Technical Pearls

- Extended lateral approach, with a subperiosteal flap
- Anatomical reduction with a congruous articular surface
- Stable fixation with interfragmentary compression

8 Outcome Clinical Photos and Radiographs

See Figs. 8 and 9.

9 Avoiding and Managing Problems

- Incorrect evaluation of the amount of displacement.
- Surgical approach with inadequate exposure.

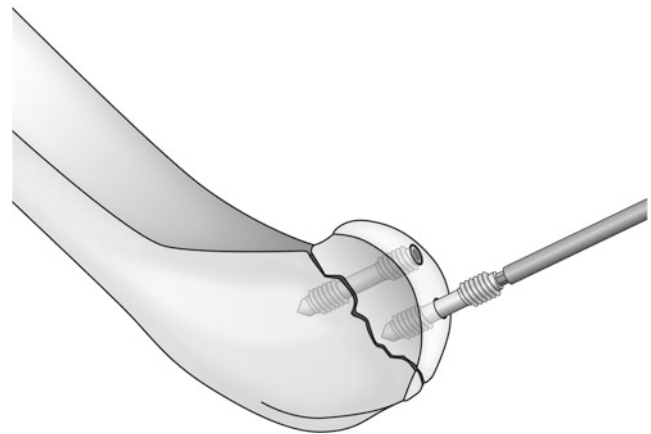


Fig. 7 A drawing showing the two headless fixation fracture, with double-threaded compression screw. The orientation of the screws goes to anterior to posterior

- Neurologic injury (posterior interosseous nerve).
- Instability that is caused by excessive detachment of the ulnar collateral ligament.
- Metaphyseal comminution.
- Insufficient implants for stable fixation.



Fig. 8 Postoperative X-ray AP view with fixation using two headless double-threaded compression screws from anterior to posterior

- Avoid extended postoperative immobilization.
- Degenerative arthritis due to joint incongruity.

10 Cross-References

- [Radial Neck Fracture: Open Reduction](#)
- [Transphyseal Distal Humerus Fracture](#)



Fig. 9 Postoperative lateral X-ray

References and Suggested Readings

- Bryan RS, Morrey BF (1985) Fractures of the distal humerus. In: Morrey BF (ed) *The elbow and its disorders*. Saunders, Philadelphia, pp 325–333
- Letts M, Rumball K, Bauermeister S, McIntyre W, D’astous J (1997) Fractures of the capitellum in adolescents. *J Pediatr Orthop* 17(3):315–320
- McKee MD, Jupiter JB, Bamberger HB (1996) Coronal shear fractures of the distal end of the humerus. *J Bone Joint Surg Am* 78(1):49–54
- Ruchelsman DE, Tejwani NC, Kwon YW, Egol KA (2008) Open reduction and internal fixation of capitellar fractures with headless screws. *J Bone Joint Surg Am* 90(6):1321–1329
- Trinh TQ, Harris JD, Kolovich GP et al (2012) Operative management of capitellar fractures: a systematic review. *J Shoulder Elb Surg. American Shoulder and Elbow Surgeons ... [et Al.]*, 21(11):1613–1622
- Vaishya R, Vijay V, Jha GK, Agarwal AK (2016) Open reduction and internal fixation of capitellar fracture through anterolateral approach with headless double-threaded compression screws: a series of 16 patients. *J Shoulder Elb Surg. American Shoulder and Elbow Surgeons ... [et Al.]*, 25(7):1182–1188

Medial Epicondyle Fractures

B. David Horn and Andrew Gambone

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Abstract

A 15-year-old male high school wrestler presented to an outside hospital with acute right elbow pain and ulnar nerve paresthesia after sustaining a fall onto his outstretched right arm during a match. Radiographs demonstrated a displaced right medial epicondyle fracture. After discussion with the patient and his family, a decision was made to proceed with surgical management. The patient was taken to the operating room and placed in the prone position with the right arm supported over a radiolucent board and bump. A medial approach to the elbow was performed and the ulnar nerve was visualized. The fracture was reduced and provisionally stabilized with a wire. A 4.0 mm partially threaded cannulated screw was then used for definitive fracture fixation. The patient was then placed in a long arm cast and elbow range-of-motion exercises

were initiated 1 week after surgery. His ulnar nerve paresthesia's resolved over the course of 2 weeks. Three months after surgery, the patient was pain-free and had full right elbow motion, at which time he returned to full activities.

1 Brief Clinical History

A 15-year-old male high school wrestler initially presented to an outside hospital with acute pain at the right elbow after sustaining a fall onto an outstretched arm during a wrestling match. Radiographs taken in the emergency department showed a displaced right medial epicondyle fracture (Figs. 1, 2, 3, and 4). Physical exam was significant for pain and swelling over the medial elbow and decreased sensation over the ulnar nerve distribution. There was mild tenderness over his lateral elbow. The right upper extremity was provisionally splinted and the patient was discharged home with instructions to follow-up as an outpatient for further care. The patient was seen in the orthopedic outpatient clinic 10 days later at which time he was still experiencing decreased

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Fig. 1 AP radiograph of the right elbow



Fig. 2 Lateral radiograph of the right elbow

sensation over the right ulnar nerve distribution. The patient is right-hand dominant. Given the patient's continued ulnar nerve paresthesia as well as his desire to return to competitive sports, operative management was recommended. Informed consent for the procedure was obtained after a discussion of the risks and benefits of operative versus nonoperative treatment with the patient and his parents.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4.



Fig. 3 External oblique radiograph of the right elbow

3 Preoperative Problem List

1. Displaced right medial epicondyle fracture
2. Ulnar nerve paresthesia
3. Instability of the elbow to valgus stress
4. Medial swelling and ecchymosis

4 Treatment Strategy

Surgical indications for medial epicondyle fractures vary greatly in the literature. The degree of fracture displacement, elbow stability, and neurological symptoms are relative indications for operative management, while an incarcerated fracture fragment in the elbow joint is considered an absolute indication (Stans and Lawrence 2015). Many displaced medial epicondyle fractures treated without surgery may heal with residual valgus instability of the elbow, which may cause difficulties in individuals who require a stable elbow such as baseball pitchers and gymnasts (Lawrence et al. 2013). Therefore, one goal of surgery is to obtain anatomical reduction of the fracture to avoid any ligamentous laxity and elbow instability. In addition, the prolonged immobilization required for nonoperative treatment of these



Fig. 4 Internal oblique radiograph of the right elbow

fractures frequently results in elbow stiffness that may take months to resolve. Operative management with stable fixation allows for early range of motion which should decrease elbow stiffness (Stepanovich et al. 2016). Depending on the size of the epicondylar fragment, a 4.0 or 4.5 mm cannulated screws can be used to provide stable fixation and allow for early motion. Traditionally, the patient is positioned supine with the operative arm supported over a radiolucent board or table. The senior author (BDH) prefers prone or lateral positioning of the patient with the operative arm supported by a radiolucent arm board or roller (Fig. 5). This allows for easy and complete access to the medial and lateral aspects of the elbow. In addition, prone positioning produces gentle varus stress at the elbow, facilitating reduction of the fracture.

5 Basic Principles

Medial epicondyle fractures of the humerus are common injuries in children. Most occur in patients 9–14 years of age, with a higher incidence occurring in males. About 50% of these fractures are associated with elbow dislocations, which may result in incarceration of the medial epicondyle in the elbow



Fig. 5 Prone positioning with arm over bolster

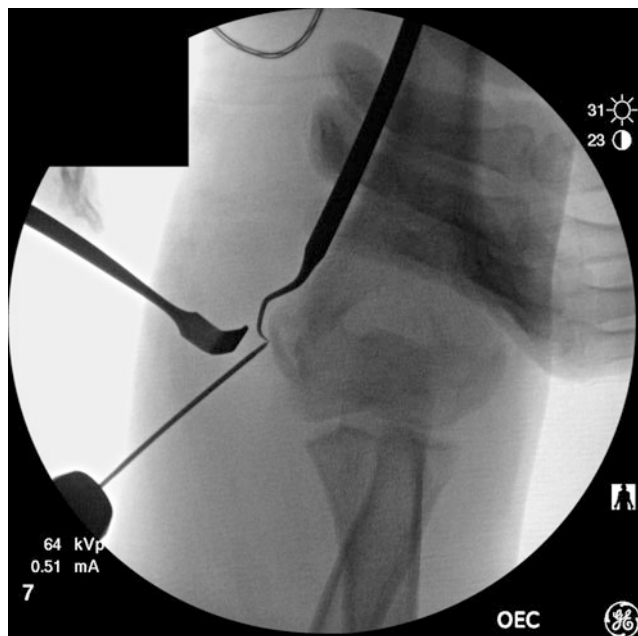


Fig. 6 Intraoperative reduction image

joint (Stans and Lawrence 2015). Understanding the anatomy and development of the elbow is important when evaluating these injuries. Ossification of the medial epicondyle begins at



Fig. 7 Intraoperative wire position on lateral

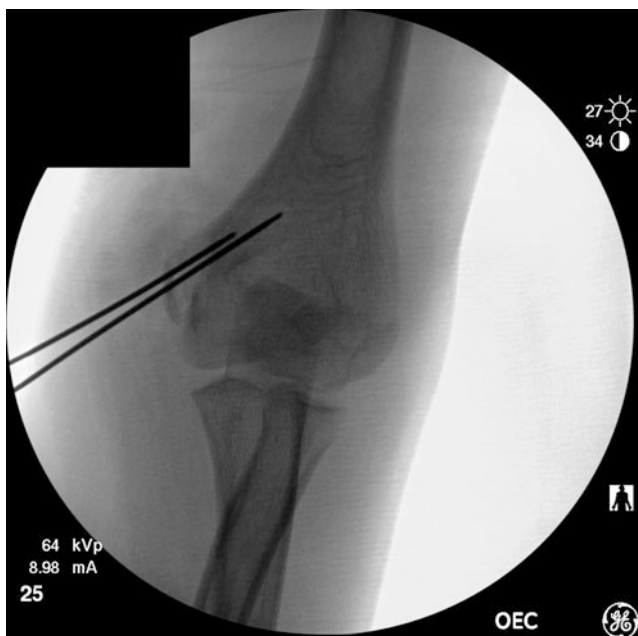


Fig. 8 Intraoperative second wire placement

4–6 years of age. It is the last ossification center to fuse with the metaphysis at approximately 15 years of age (Gottschalk et al. 2012). Mechanism of injury can be the result of direct trauma to the posterior or posteromedial aspect of the elbow or be secondary to an avulsion of the medial epicondyle from either a fall onto an outstretched hand or overuse injury. Patients normally present with pain, tenderness, and swelling over the medial elbow. Since the medial epicondyle is a relatively



Fig. 9 Photo of elbow with wires



Fig. 10 Intraoperative AP screw with washer

posterior structure, axial and oblique views may help show fracture displacement. Computerized tomography (CT) will also accurately show fracture morphology (Edmonds 2010;



Fig. 11 Intraoperative lateral screw with washer

Souder et al. 2015). Basic principles of operative treatment include identification of the ulnar nerve (to help avoid intraoperative ulnar nerve injury), anatomic reduction of the fracture, and stable fixation (allowing for early motion).

6 Images During Treatment

See Figs. 5, 6, 7, 8, 9, 10, and 11.

7 Technical Pearls

In the prone position, care should be taken to pad bony prominences and use appropriate bolsters (Fig. 5). If, when prone, the operative arm is placed on a hand table, there needs to be sufficient shoulder internal rotation present to allow for adequate medial exposure at the elbow. Ensuring proper C-arm positioning and imaging prior to prepping and draping is essential for adequate intraoperative fluoroscopic imaging. The ulnar nerve should be identified, although it typically does not need to be mobilized or transposed. The apophyseal cartilage should be removed from the fracture site prior to fixation. A 4 or 4.5 mm cannulated screw is commonly used; bicortical fixation is not required and care should be taken to keep the screw within the medial column of the distal humerus. A second wire may be placed temporarily in order to prevent the fragment from rotating during screw placement (Figs. 8 and 9). The medial epicondyle fragment is easily split when tightening the screw. A washer may be used to augment fixation of the fragment (Figs. 12 and 13).



Fig. 12 AP right elbow



Fig. 13 Lateral right elbow

8 Outcome Clinical Photos and Radiographs

See Figs. 12 and 13.

9 Avoiding and Managing Problems

Proper radiographs, careful preoperative planning, and a strict postoperative rehabilitation protocol are essential for avoiding problems when surgically treating medial

epicondyle fractures. Obtaining high-quality AP and lateral radiographs are essential. Internal oblique and axial radiographs, as well as CT, may better characterize the amount and direction of fracture displacement (Edmonds 2010; Souder et al. 2015). Intraoperative visualization of the ulnar nerve is essential to help prevent nerve injury. The goal is to obtain stable, anatomic reduction of the fracture so screw fixation of the fracture is preferred. Care should be taken to avoid fragmenting the epicondyle which could compromise stability. Prolonged immobilization leads to elbow stiffness and may result in long-term loss of range of motion (Lawrence et al. 2013). The authors recommend early active range-of-motion exercises to help prevent this.

10 Cross-References

► Medial Condyle Fracture

References and Suggested Readings

- Edmonds EW (2010) How displaced are “nondisplaced” fractures of the medial humeral epicondyle in children? Results of a three-dimensional computed tomography analysis. *J Bone Joint Surg Am* 92(17):2785–2791
- Gottschalk HP, Eisner E, Hosalkar HS (2012) Medial epicondyle fractures in the pediatric population. *J Am Acad Orthop Surg* 20:223–232
- Lawrence JT, Patel NM, Ganley TJ et al (2013) Return to competitive sports after medial epicondyle fractures in adolescent athletes: results of operative and nonoperative treatment. *Am J Sports* 41:1152–1157
- Souder CD, Farnsworth CL, Edmonds EW et al (2015) The distal humerus axial view: assessment of displacement in medial epicondyle fractures. *J Pediatr Orthop* 35:5
- Stepanovich M, Bastrom TP, Munch J et al (2016) Does operative fixation affect outcomes of displaced medial epicondyle fractures? *J Child Orthop* 10:413
- Stans AA, Lawrence JT (2015) Dislocations of the elbows, medial epicondylar humerus fractures. In: Flynn JM, Skaggs DL, Waters PM (eds) *Rockwood and Wilkins’ fractures in children*, 8th edn. Wolters Kluwer, Philadelphia, pp 651–700

Medial Condyle Fracture

L. Reid Nichols, David Tager, and Daniel Grant

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Abstract

The medial condyle fracture is an uncommon injury in the pediatric population, accounting for 1–2% of all distal humeral fractures. A corollary to this fracture is the lateral condyle fracture, by comparison accounting for 17% of all distal humeral fractures. The mechanism for this injury is valgus load applied to an extended elbow, although other mechanisms have also been proposed. A thorough understanding of distal humeral anatomy and ossification is essential for proper diagnosis and treatment of this fracture. From proximal to distal, the medial condyle fracture

travels from the medial condylar metaphysis typically through the common physal line of the trochlea and capitellum as in Milch type I injuries. Alternatively, the fracture line can pass through the capitulotrochlear groove as in Milch type II injuries. The medial condyle fracture is comprised of the medial epicondyle and the trochlea, which ossify at 5/7.5 years and 9/10.7 years, respectively, for girls/boys. The disparate ossification of these epiphyses may lead to misdiagnosis in younger patients with apparent isolated medial epicondylar fractures. In such patients, the medial condyle fracture is comprised of the ossifying medial epicondyle and the cartilaginous trochlea. Medial epicondyle fractures are Salter Harris IV physal fractures and involve the elbow joint. Minimally displaced fractures may be treated with long arm cast immobilization and close surveillance. Open reduction and internal fixation with smooth Kirschner wires or screw fixation is indicated for greater displacement to avoid nonunion and long-term morbidity.

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1 Brief Clinical History

A 9-year-old female was jumping on a trampoline when she fell off, landing on her right elbow. The exact position of the patient's elbow on impact was not recalled. She presented to an outside emergency department where radiographs confirmed a fracture of the medial condyle of the distal humerus with a concomitant elbow dislocation. The right elbow was reduced and splinted. The patient was referred to the pediatric orthopedic department for further evaluation and management the subsequent day. Physical examination performed in the clinic was remarkable for an anterior interosseus nerve palsy. Significant swelling was appreciated around the elbow, and pain was reported with any elbow motion. The injury was closed.

2 Preoperative Clinical Photos and Radiographs

See Images 1, 2, 3 and 4.

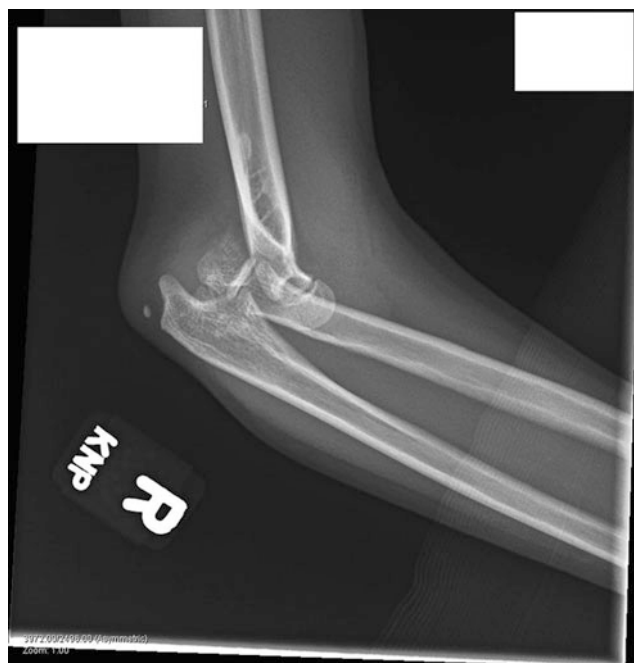


Image 2 Injury radiograph: lateral of the right elbow demonstrating the medial condyle fracture dislocation



Image 1 Injury radiograph: AP of the right elbow demonstrating the medial condyle fracture dislocation



Image 3 Postreduction AP radiograph of the right elbow demonstrating the medial condyle fracture



Image 4 Postreduction lateral radiograph of the right elbow demonstrating the medial condyle fracture

3 Preoperative Problem List

Complete medical and surgical history was unremarkable. The patient did not take any medications regularly and did not have allergies.

4 Treatment Strategy

Medial condyle fractures that are minimally displaced can be treated nonoperatively with cast immobilization. As they are intra-articular, medial condyle fractures displaced greater than 2 mm should undergo open reduction and internal fixation (Leet et al. 2002). Oblique radiographs of the elbow can aid in characterization of the medial condyle fracture. Determining the extent of displacement in younger patients can pose a challenge. MRI or an intraoperative arthrogram of the elbow can help determine the extent of displacement and need for operative intervention (Flynn et al. 2015; Papavasiliou et al. 1987). As in a lateral condyle fracture, internal stabilization of the fracture can be achieved with smooth pin fixation, including a transverse pin which traverses parallel to the joint and a divergent pin that engages the medial column of the distal humerus. A third pin may be added as necessary. Our patient was positioned supine, and

the arm was placed on a radiolucent hand table. A direct medial approach was utilized to simultaneously view the fracture site, including its intra-articular extension (Bensahel et al. 1986), in addition to visualizing and protecting the ulnar nerve which crosses through the cubital tunnel in close proximity. Once an open reduction of the joint surface was achieved and adequate reduction of the remaining fragment was confirmed, the fracture was stabilized with three 1.5 mm smooth Kirschner wires.

5 Basic Principles

In a displaced medial condyle fracture that undergoes open reduction and internal fixation, anatomic reduction of the joint surface is critical. This is facilitated by an open medial approach and anterior distal humeral dissection, which allows for visualization of the joint surface. Dissection of the medial condyle fracture should not proceed posterior to the distal humerus or along the medial aspect of the trochlea to preserve their vascular supply and prevent avascular necrosis (Flynn et al. 2015). Internal fixation of the medial condyle fracture can generally be achieved with smooth 1.5 or 2.0 mm Kirschner wires. The wires are left superficial to the skin, and they are bent and cut prior to cast application. In older patients, cannulated lag screws may be used. In the majority of patients, the elbow is immobilized for 4 weeks in a long arm cast. At 4 weeks, the pins are removed in clinic and gentle elbow range of motion is initiated.

6 Images During Treatment

See Images 5 and 6.

7 Technical Pearls

In younger patients prior to the ossification of the trochlea, it is critical to distinguish medial epicondyle fractures from medial condyle fractures. In the latter, the cartilaginous trochlea is attached to the medial epicondyle and is not appreciated on plain radiographs. Fracture morphology and displacement can be distinguished by MRI of the elbow or intraoperative arthrography (See Images 7 and 8). Intraoperatively during exposure of the anterior distal humerus, a lighted suction tip or head lamp can enhance visualization of the distal humeral articular surface and facilitate reduction. An open medial

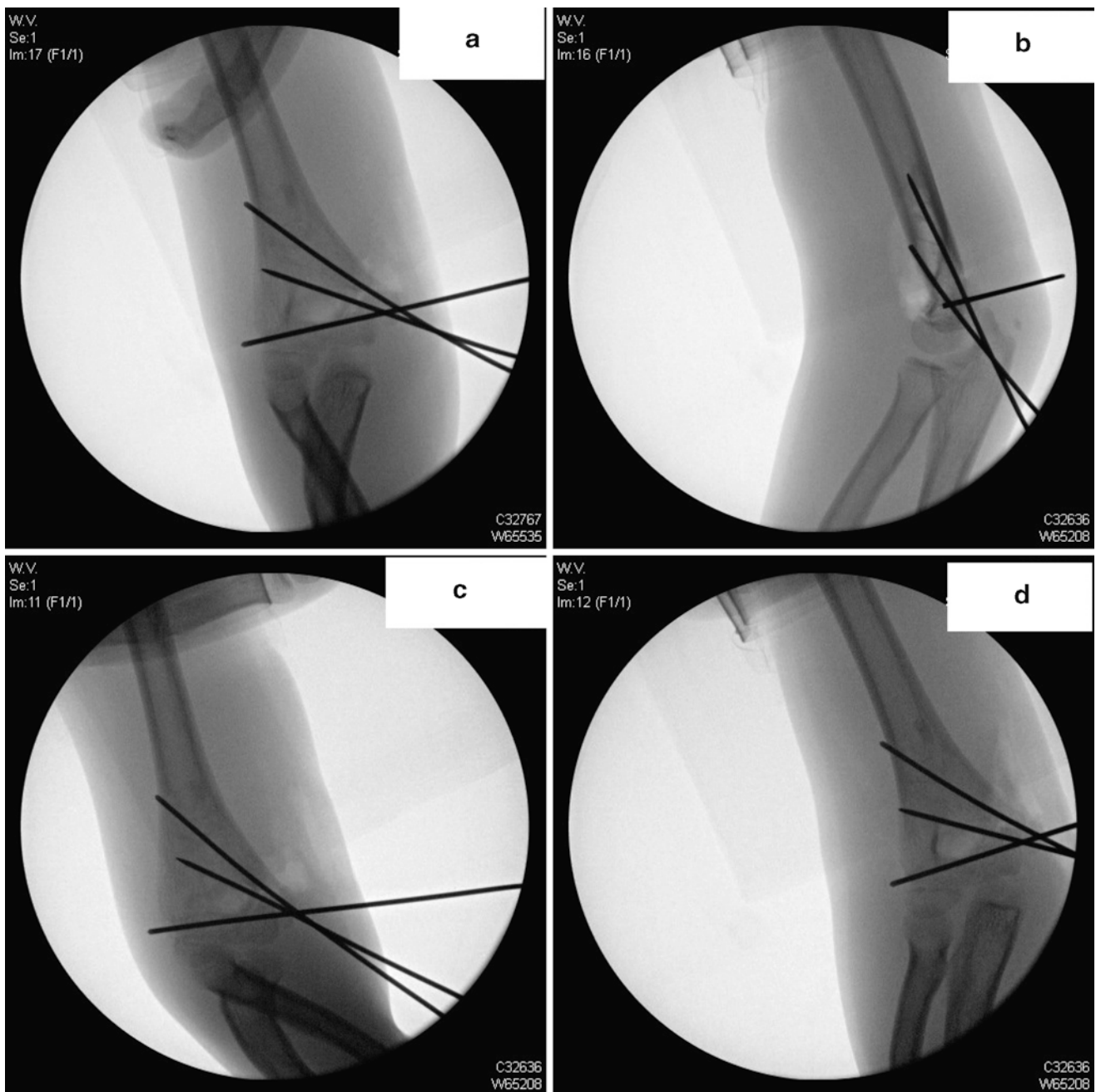


Image 5 (a–d) AP, lateral, and oblique fluoroscopic images of the medial condyle fracture reduced and stabilized with three 1.5 mm smooth Kirschner wires

approach allows for adequate protection of the ulnar nerve throughout the case.

8 Outcome Clinical Photos and Radiographs

See Images 9 and 10.

9 Avoiding and Managing Problems

Paramount for this fracture is making the correct diagnosis in a younger patient prior to the ossification of the trochlea. A displaced medial condyle fracture carries distinctly different sequelae compared with a displaced medial epicondyle fracture, which is extra-articular. Untreated displaced medial

Image 6 Representative intraoperative photograph of an open approach to the medial condyle in a separate case. The patient's hand is to the right of the photograph. Note the close proximity of the ulnar nerve (black arrowhead) to the medial condyle of the distal humerus (white arrowhead)

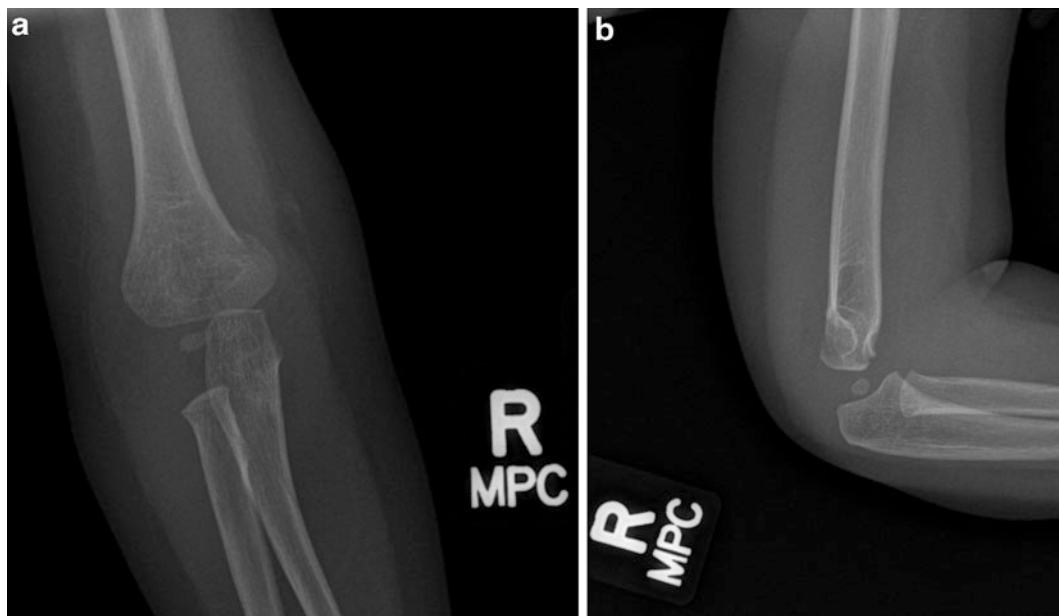
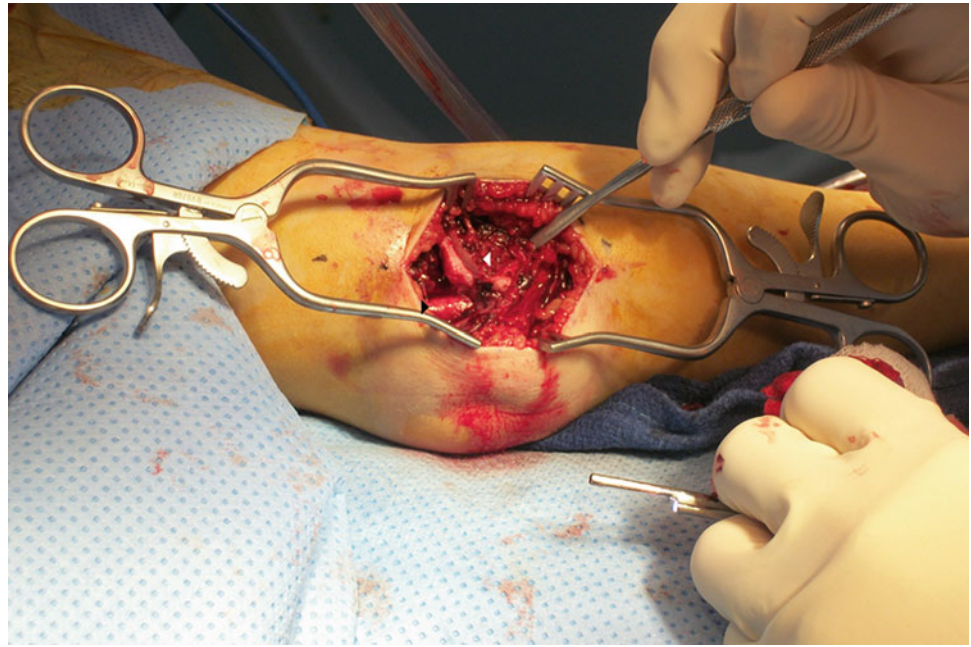


Image 7 (a, b) AP and lateral of a right elbow in a 2-year-old male with a displaced medial condyle fracture

condyle fractures can lead to nonunion, continued lateral distal humerus growth, and subsequent cubitus varus. Resultant joint deformity can lead to motion limitations and long-term arthrosis. As mentioned, MRI and/or arthrography can be used to distinguish the two entities. Minimally displaced or nondisplaced medial condyle fracture should be followed closely to detect and treat late

displacement promptly. Medial condyle fractures that heal uneventfully can lead to both cubitus varus and valgus. Cubitus varus can result from disturbed growth of the medial condyle after healing, and cubitus valgus can result from growth stimulation relative to the lateral condyle after healing. During exposure of the fracture in the open medial approach, dissection should be avoided posterior to the

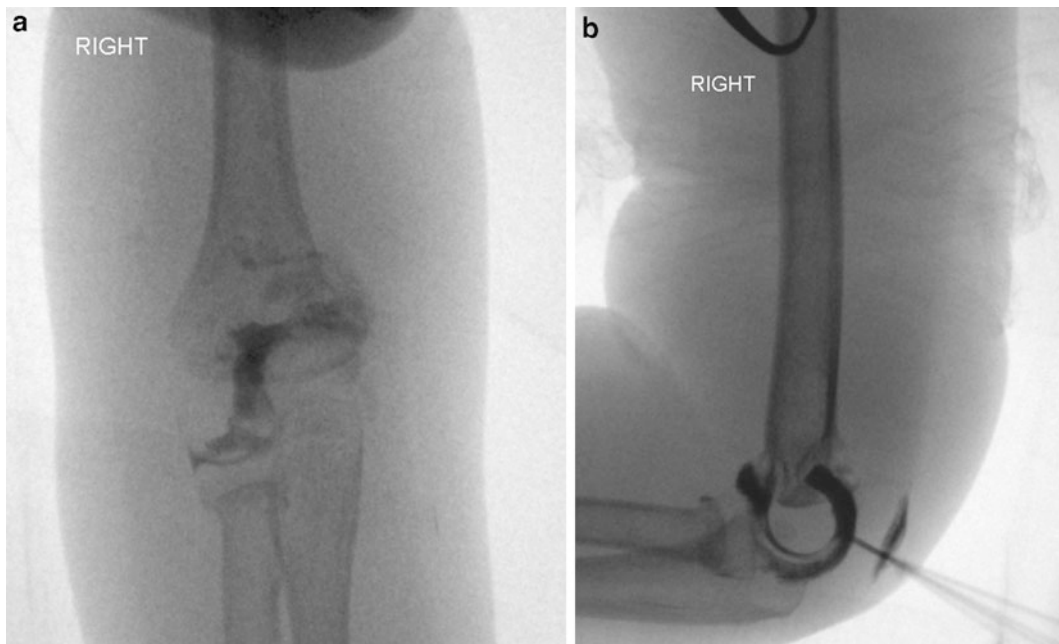


Image 8 (a, b) AP and lateral of an intraoperative arthrogram which confirms the extent of displacement of the medial condylar fragment

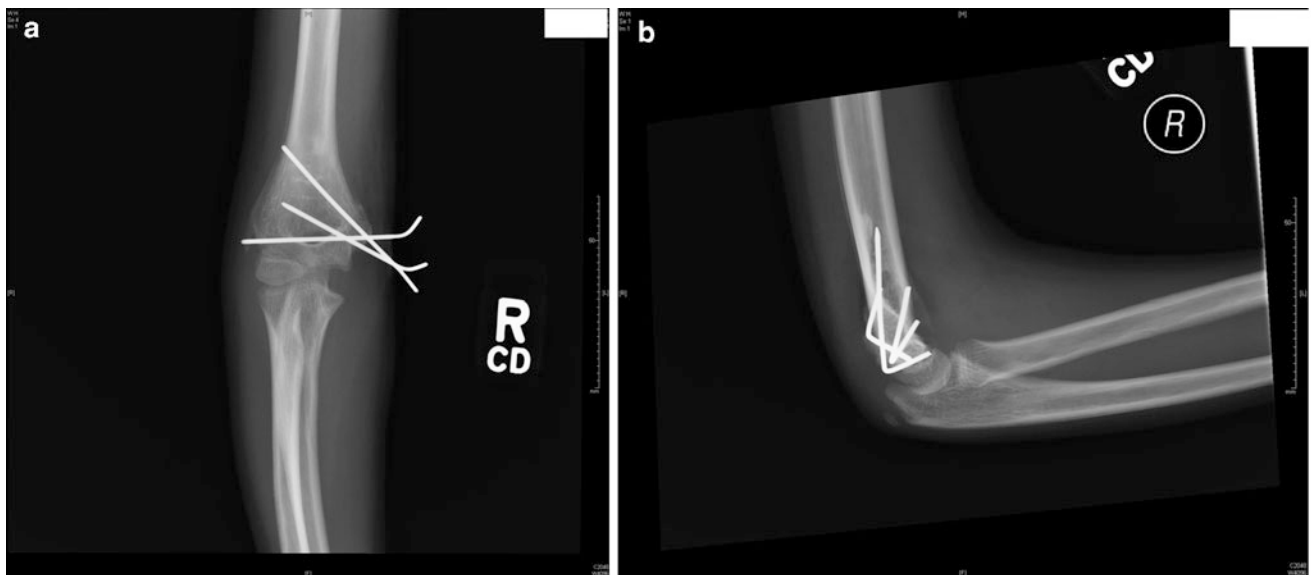


Image 9 (a, b) AP and lateral radiographs of the right elbow 4 weeks postoperative prior to pin removal. Abundant callous deposition has occurred medial and lateral to the distal humerus and the fracture is well-healed



Image 10 (a, b) AP and lateral radiographs of the right elbow 8 weeks postoperative demonstrating mild heterotopic ossification along the course of the lateral collateral ligament. This occurred in the absence

of any open exposure on the lateral side of the elbow. Unfortunately, this ossification would progress and lead to limitations of this patient's range of motion

medial condyle fragment to protect its vascular supply and avoid avascular necrosis.

Direct visualization of the ulnar nerve should be performed to protect the nerve from injury during pin or screw placement. Transient neurapraxia is possible from the exposure of the nerve, and parents should be warned prior to surgery.

10 Cross-References

- [Displaced Elbow Lateral Condyle Fracture: Treatment with a Cannulated Screw](#)
- [Medial Epicondyle Fractures](#)
- [Minimally Displaced Lateral Condyle Fractures of the Elbow: Treatment with Arthrography and Percutaneous Cannulated Screw Fixation](#)

References and Suggested Reading

- Bensahel H et al (1986) Fractures of the medial condyle of the humerus in children. *J Pediatr Orthop* 6(4):430–433
- Flynn JM, Skaggs DL, Waters PM (2015) *Rockwood & Wilkins' fractures in children*. Wolters Kluwer Health, Philadelphia, PA
- Leet AI, Young C, Mark Hoffer M (2002) Medial condyle fractures of the humerus in children. *J Pediatr Orthop* 22(1):2–7
- Papavasiliou V, Nenopoulos S, Venturis T (1987) Fractures of the medial condyle of the humerus in childhood. *J Pediatr Orthop* 7(4):421–423

An Elbow Dislocation With and Without Additional Fractures

Arnold T. Besselaar and Florens Q. M. P. van Douveren

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Abstract

Dislocations of the ulnohumeral joint occur in approximately 3–6% of elbow injuries in children. Peak incidence occurs mostly around the second decade of life because of the closure of the physal structures around the pediatric elbow during that period. It is important to recognize potential associated medial epicondyle fracture dislocations, which occur in several series between 33% and 55%. Infrequently lateral humeral condyle fractures are associated with posterior dislocations. Injuries to the ulnar and radial collateral ligaments should be expected and examined for.

One-year post-injury, the patient was again examined. Full range of motion, no instability, and a painless activity level were noted. The X-ray (Fig. 3a, b) showed no abnormalities or posttraumatic changes. Clinical function tests showed full range of motion (Fig. 4a, b, c). Patient was discharged.

1 Brief Clinical History Case 1: No Additional Fractures

A 9-year-old boy sustained a fall on an outstretched arm during a soccer game. He presented to our emergency department with a flexed painful right elbow. The neurovascular status was normal. X-rays (Fig. 1a, b) showed a posterior dislocation of the right elbow without associated fractures. Sedation with 50 (2–3.5 mg/kg) mg IV propofol was used while monitoring the patient. Reduction by the push method was successful. Postreduction stability tests showed no tendency to redislocation. Postreduction films were performed; no fractures were identified (Fig. 2a, b). The patient was immobilized in a long arm plaster for 3 weeks. He was examined again after cast removal; the elbow showed no valgus or varus instability.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

- Dislocation of ulnohumeral joint
- Additional bony and or ligamentous lesions?
- Preoperative planning

4 Basic Principles

- Reduce the dislocation and search for additional disruptions or fractures.
- X-rays and rarely CT scanning till all fractures are visible.
- Perform preoperative planning.

Fig. 1 (a) Posterolateral dislocation, *right* elbow, sagittal plane. (b) Posterolateral dislocation, *right* elbow, AP view



Fig. 2 (a) Postreduction film, right elbow, AP view. (b) Postreduction film, right elbow, sagittal plane

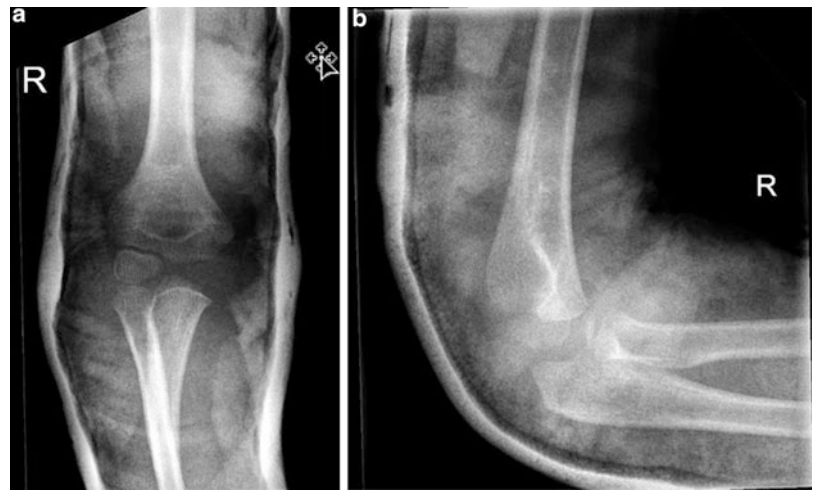


Fig. 3 (a) Follow-up X-ray, 1-year post-trauma, right elbow, AP view. (b) Follow-up X-ray, 1-year post-trauma. Sagittal view

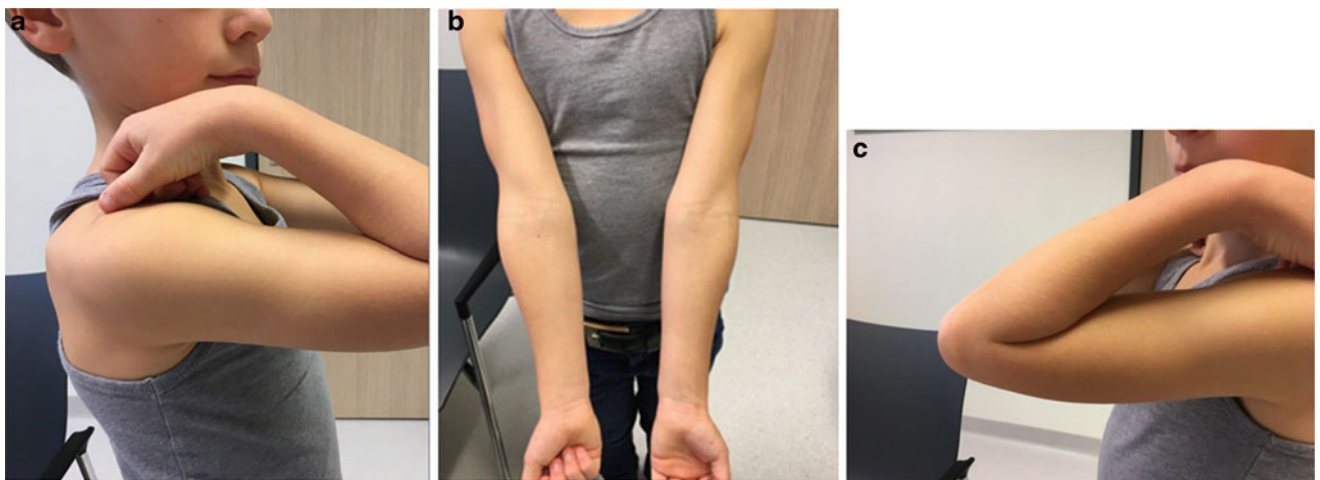
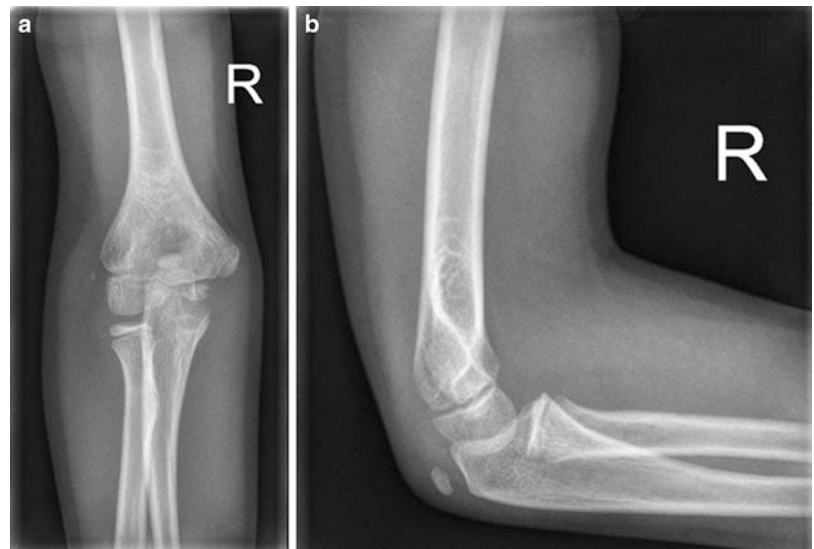


Fig. 4 (a) Follow-up clinical pictures. One-year post-trauma elbow fully flexed. (b) Follow-up clinical pictures. One-year post-trauma elbow fully extended. (c) Follow-up clinical pictures. One-year post-trauma elbow fully flexed

5 Images During Treatment

See Fig. 2.

6 Technical Pearls

- The push method as a reduction technique is safe and reliable.
- Use any form of sedation; it is for patient and parent traumatizing to have a difficult reduction in an awake child.
- Test stability during the procedure when the child is sedated.

7 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

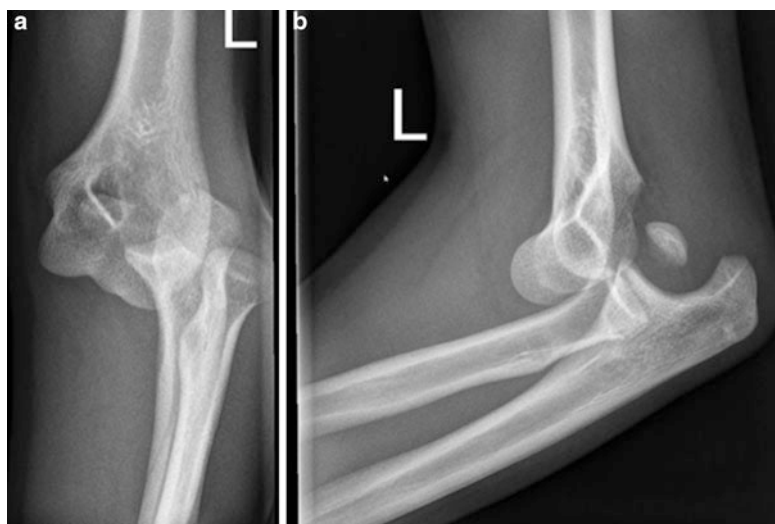
8 Brief Clinical History Case 2: Associated Medial Epicondyle Fracture

A 12-year-old girl sustained a soccer injury. She presented to the emergency department with pain and a dislocated left elbow. Reduction with the push method succeeded under sedation with propofol. The X-rays after reduction showed a fracture of the medial epicondyle a dislocated fracture (Fig. 5).

9 Preoperative Clinical Photos and Radiographs

See Fig. 5.

Fig. 5 (a, b) AP and lateral view of a dislocated left elbow with associated medial epicondyle fracture



10 Preoperative Problem List

- Dislocation of ulnohumeral joint
- Additional medial epicondyle fracture and possible ligamentous lesions
- Preoperative planning
- Open physes

11 Basic Principles

- Reduce the dislocated elbow and search for additional injuries.
- Test for stability after fixation of the fracture.
- Multiple view X-rays and rarely CT scanning are used to visualize the complete injury.
- Perform a preoperative plan including positioning of the patient prone (see Fig. 6).
- Considerable variation in opinions between operative and nonoperative treatment exists. In this case, the associated medial epicondyle fracture was dislocated > 15 mm and entrapped in the joint, leading to an indication for operative treatment. Although theoretically fixation is possible with K-wires or screws, our preference is to fix with a cannulated screw. The ulnar nerve should be visualized and protected.

12 Images During Treatment

See Fig. 6.

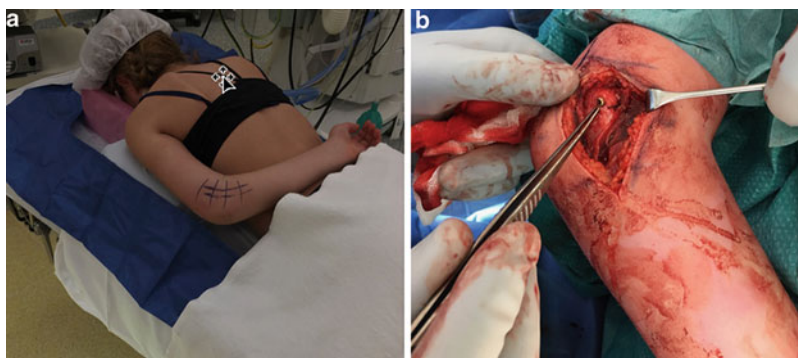


Fig. 6 (a) Patient was positioned prone with the hand on the ipsilateral hip. In this position, the medial epicondyle is very well exposed and muscles are relaxed. (b) Intraoperative view of the fixed medial

epicondyle. The ulnar nerve was identified in the lower part of the picture and protected with a vessel loop (already removed in the picture). A cannulated 4.0 screw (DePuy Synthes) was used for fixation

Fig. 7 (a, b) Radiographs show medial epicondyle is reduced, elbow is aligned and stable, and hardware is in good position



13 Technical Pearls

- Prone position is recommended.
- Identify and protect ulnar nerve.
- Reattach capsule and ligaments accurately.

14 Outcome Clinical Photos and Radiographs

See Fig. 7.

15 Brief Clinical History Case 3: Associated Lateral Condyle Fracture

An 8-year-old boy, who fell during downhill mountain bike, sustained a fall directly on the lateral side of his elbow. He was brought in our emergency department with a flexed

painful right elbow. The neurovascular status was unaffected. X-rays (Fig. 8a, b) showed a medial dislocated right elbow with a Salter-Harris II, lateral condyle fracture, and no associated radial head fracture. The fracture is located medial to the capitellum. The postop X-rays are shown in Fig. 9. The patient was immobilized in an above arm plaster for 6 weeks. He was examined again after cast removal; the elbow showed no valgus or varus instability. One-year post-injury, the patient was again examined. Full range of motion, no instability, and a painless activity level were seen. The X-rays after 1-year postop (Fig. 10) and 2-year postop show a mild growth disturbance of the trochlea, which stayed stable in time without any loss of function.

16 Preoperative Clinical Photos and Radiographs

See Fig. 8.

Fig. 8 (a, b) AP and lateral view of the right distal humerus with a dislocated ulnohumeral joint and an associated lateral condyle fracture



Fig. 9 (a, b) Postoperative films, AP and lateral. Two Kirschner wires were used to fix the lateral condyle fracture. A plaster was used for 4 weeks till the K-wires were removed

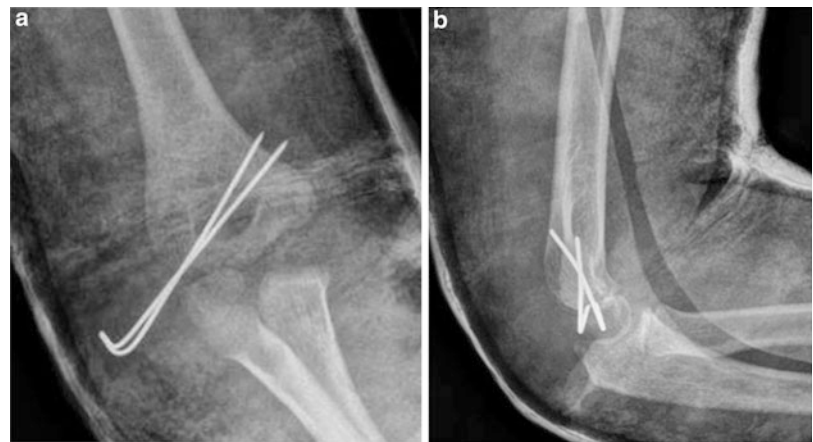


Fig. 10 (a, b) AP and lateral views of the right upper arm 1-year post-trauma. A mild growth disturbance of the trochlea can be seen. The lateral view shows still some remodeling. Function was unrestricted, there was no axial deformation and no pain at all



17 Preoperative Problem List

- Dislocation of ulnohumeral joint
- Additional lateral condyle fracture with dislocation
- Preoperative planning
- Open physes

18 Basic Principles

- Reduce the dislocation and search for additional injuries.
- Test for stability after fixation of the fracture.
- Multiple view X-rays and rarely CT scanning are used to visualize the complete injury.
- Perform a preoperative plan.

19 Images Post Operatively

See Fig. 9.

20 Technical Pearls

- Use image identification during the operation. Discrete dislocations can be difficult to assign in the operation area.
- Use smooth K-wires to damage the growth plate as little as possible.
- K-wires can be cut outside the skin.

21 Outcome Clinical Photos and Radiographs

See Fig. 10.

22 Treatment Strategy

Treatment will differ according to the injury. An isolated elbow dislocation can be treated by a closed reduction and immobilization in a cast for a maximum of 3 weeks. Early instability postreduction can be treated by direct ligamentous repair in the acute phase. In case of chronic instability after reduction, late repair can be discussed.

Reduction maneuvers can be divided into push and pull techniques. Our preference is the push technique because of his gentle and controlled way of reduction (Stan and Stephen 2009). An advantage of reducing the fracture in an anesthetized or sedated child is the possibility of relied testing of the instability together with the avoidance of pain and anxiety in the injured child. Associated fractures should be treated

operatively in most cases. Medial epicondyle or lateral condyle fractures should be stabilized with screws or K-wires, dependent of the size of the fragment (Skelley and Chamberlain 2015). Radial neck fractures can be stabilized by ESIN (Parikh et al. 2014; Di Gennaro et al. 2013).

Posterior or posterolateral dislocations are most common, but dislocations in other directions anterior, medial, lateral, and convergent and divergent also occur (Lieber et al. 2012; Kozin et al. 2015).

Recently Murphy published a complication rate in elbow dislocations of 14% (Murphy et al. 2015). The presence of associated fractures was associated with a higher risk of decreased flexion, fewer excellent functional outcomes, and a significant higher complication percentage (Subasi et al. 2015). Immobilization in a cast or hinged brace should be maximized for 2–3 weeks (Murphy et al. 2015). Thorough neurologic exam should rule out neurological impairment mostly according toward the ulnar and median nerve.

23 Basic Principles

- Reduce the dislocation and search for additional disruptions or fractures.
- X-rays and rarely CT scanning till all fractures are visible.
- Perform preoperative planning.

24 Avoiding and Managing Problems

- Do not overlook additional fractures.
- Search for instability and treat it early.

25 Cross-References

► [Medial Epicondyle Fractures](#)

References and Suggested Readings

- Di Gennaro GL, Spina M, Fosco M, Antonioli D, Donzelli O (2013) Dislocations of the elbow in children: long-term follow-up. *Musculoskelet Surg* 97(Suppl 1):3–7
- Kozin SH, Abzug JM, Safier S, Herman MJ (2015) Complications of pediatric elbow dislocations and monteeggia fracture-dislocations. *Instr Course Lect* 64:493–498
- Lieber J, Zundel SM, Luithle T, Fuchs J, Kirschner HJ (2012) Acute traumatic posterior elbow dislocation in children. *J Pediatr Orthop B* 21(5):474–481
- Murphy RF, Vuillermin C, Naqvi M, Miller PE, Bae DS, Shore B (2015) Early outcomes of pediatric elbow dislocation-risk factors associated with morbidity. *J Pediatr Orthop* 2015 Nov 3
- Parikh SN, Lykissas MG, Mehlman CT, Sands S, Herrera-Soto J, Panchal A, Crawford AH (2014) Convergent and divergent

- dislocation of the pediatric elbow: two case reports and comprehensive review of literature. *J Pediatr Orthop B* 23(2):158–167
- Skelley NW, Chamberlain A (2015) A novel reduction technique for elbow dislocations. *Orthopedics* 38(1):42–44
- Subasi M, Isik M, Bulut M, Cebesoy O, Uludag A, Karakurt L (2015) Clinical and functional outcomes and treatment options for paediatric elbow dislocations: experiences of three trauma centres. *Injury* 46 (Suppl 2):S14–S18

TRASH (The Radiographic Appearance Seemed Harmless) Lesions About the Elbow

Kali Tileston and Steven L. Frick

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Abstract

In adults, fractures of the distal humerus, proximal radius, and olecranon are easily identified radiographically. In contrast, for children there exists a small subset of fractures that are challenging to identify due to the lack of ossification of the elbow epiphyses. These osteochondral fractures often appear benign on plain radiographs, as the main portion of the fracture is cartilaginous in nature. As they are difficult to identify radiographically and thus are easily missed, they are commonly referred to as “TRASH” lesions (The Radiographic Appearance Seemed Harmless). These injuries can require three-dimensional imaging to better characterize the lesion. TRASH lesions are relatively rare fractures that occur in skeletally immature children. They can include

unossified medial condyle fractures, unossified transphyseal distal humerus fractures, entrapped medial epicondyle fractures, complex osteochondral elbow fracture dislocations, osteochondral fractures with joint incongruity, radial head compression fractures with radiocapitellar subluxation, Monteggia fracture dislocations, and lateral condyle avulsion shear fractures (Waters PM, Beatty J, Kasser J (2010) *J Pediatr Orthop* 30(Supp 2):S77–S81). Failing to diagnose these fractures can lead to devastating consequences in regard to the future health of the elbow.

1 Brief Clinical History

The patient is a 2-year-old female who fell approximately 2 weeks prior to presentation. She presented to clinic with reports of pain about the elbow, decreased motion, and inability to bear weight on that extremity. She had previously sustained a right lateral condyle fracture of the distal humerus 5 months prior which had healed uneventfully, and she had regained full range of motion. Evaluation of the right arm demonstrated swelling about the elbow and a flexion-

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extension arc from 10 to 30° flexion-extension arc. She was neurovascularly intact. Radiographs of the right elbow demonstrated a congruent ulnohumeral and radiocapitellar joint. However, a small osseous fracture fragment was noted on the sagittal radiograph anterior to the distal humerus (Fig. 1a, b). A CT scan was obtained which was unable to identify the donor site. Therefore, a MRI was obtained which demonstrated a trochlear shear fracture of the distal humerus with the coronoid engaging the distal portion of the osteochondral fragment (Fig. 2a, b).

2 Preoperative Clinical Photos and Radiographs

3 Preoperative Problem List

1. Right, closed, trochlear shear osteochondral fracture of the distal humerus.

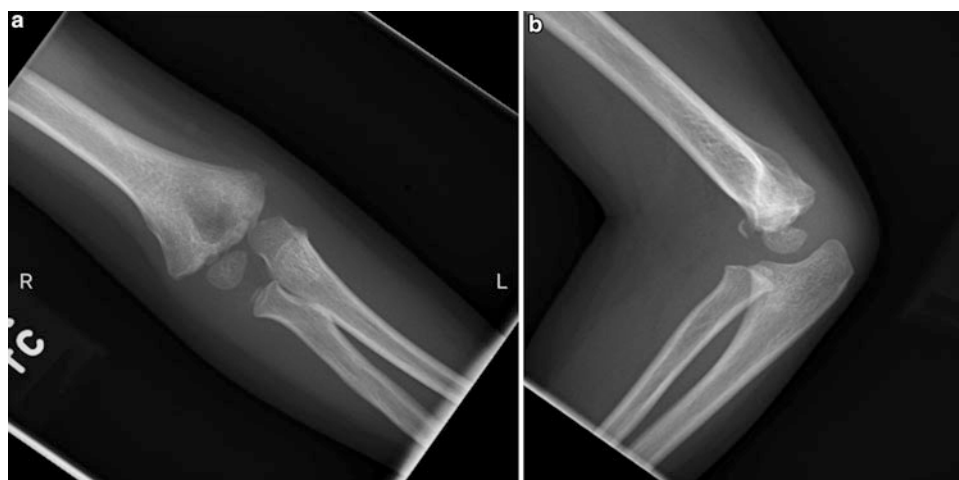
4 Treatment Strategy

Accurate characterization of these lesions is of paramount importance in order to appropriately preoperatively plan treatment. This can be performed in several ways. The first is utilization of three-dimensional imaging. Ultrasonography is inexpensive, is rapidly available in most hospitals, and does not require sedation. Depending on the skill of the musculoskeletal radiologist, they may be able to characterize the lesion and determine the size of the fragment, the donor site, and congruency of the joint. CT scans may also be obtained. However, due to the lack of ossification about the elbow in younger children, they often are of limited utility and may submit a child to unnecessary radiation. If a child is older and has increased ossification of their epiphyses, it can

be of great utility (Fig. 3a–c). MRIs without contrast provide excellent visualization of the fracture fragments including their size, orientation, and joint involvement. However, smaller children may require sedation for this procedure in order to obtain adequate imaging. Finally, intraoperative arthrograms can be useful in identifying the size and location of a fragment. However, as it is done intraoperatively, preoperative planning can be challenging.

Displaced fragments generally require operative treatment. If the fracture is extra-articular in nature and can be visualized with an arthrogram, closed reduction with percutaneous pinning may be attempted. However, many of these fragments are intra-articular and unstable. They therefore require open reduction. In patients undergoing open treatment, fixation options include Kirschner wires (K-wires), headless compression screws, mini-fragment plates and screws, bioabsorbable chondral fixation, and sutures with or without anchor fixation. K-wires are the workhorses for most pediatric fractures about the elbow (Fig. 4a–c). They have the benefit of multiple size options, removal outside of the operating room, low cost, and wide availability. Unfortunately, they do not provide compression across a fracture fragment. In fragments that are mainly chondral in nature, healing may be compromised, and compression at the fracture site could be of great utility. Headless compression screws and mini-fragment plates have the ability to provide the compression that K-wires lack. However, they can be difficult if not impossible to remove. The metallic nature of these implants also precludes future fine detail three-dimensional imaging due to scatter. Bioabsorbable chondral fixation is frequently utilized for fixation of osteochondritis dissecans lesions. They provide some level of compression and do not require removal. However, there have been case reports of implant backing out or persistent effusions (Scioscia et al. 2001; Fridén and Rydholm 1992; Barfod and Svendsen 1992). Finally, suture fixation is widely available. However, the needles required to pass the suture can cause fragmentation of the small fracture pieces, and

Fig. 1 (a, b) Radiographs at presentation demonstrating a congruent ulnohumeral and radiocapitellar joint with a small osseous fragment volar to the distal humerus



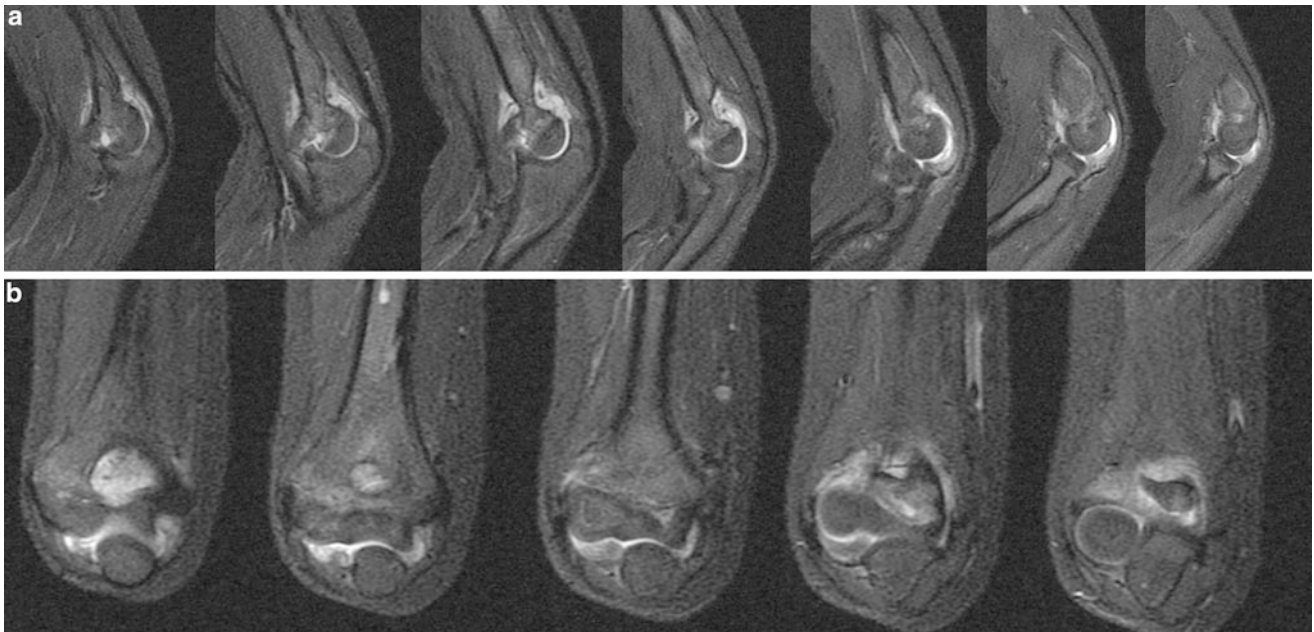


Fig. 2 (a, b) MRI demonstrating a 13×7 mm osteochondral trochlear shear fracture with the capitellum engaging the distal portion of the fragment

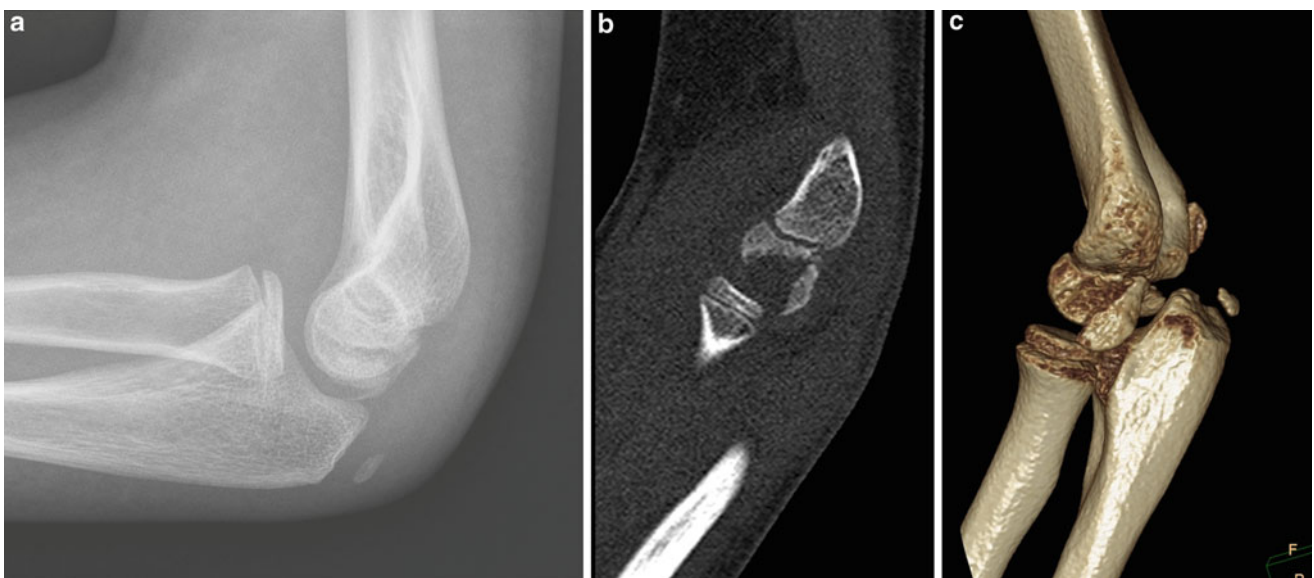


Fig. 3 A 9-year-old patient with swollen elbow with limited motion after fall on outstretched hand. (a) Lateral radiograph demonstrates a small semicircular ossific density posterior to the capitellum. (b) CT

scan demonstrates capitellar shear fragment. (c) 3D reconstruction demonstrates that the fragment is larger than appreciated from plain radiography and 2D CT scan

intra-articular suture can cause damage to the surrounding cartilage.

A salvage option if fixation of the fragments is not possible and the piece is hindering range of motion of the elbow is excision of the osteochondral fragment as long as the joint remains congruent and stable after removal. This option should be utilized only if the other treatment options listed above have failed.

5 Basic Principles

1. Open reduction and anatomic fixation is the first line of treatment for intra-articular osteochondral lesions.
2. Nonarticular fragments that do not restrict range of motion or cause joint subluxation can occasionally be managed nonoperatively.

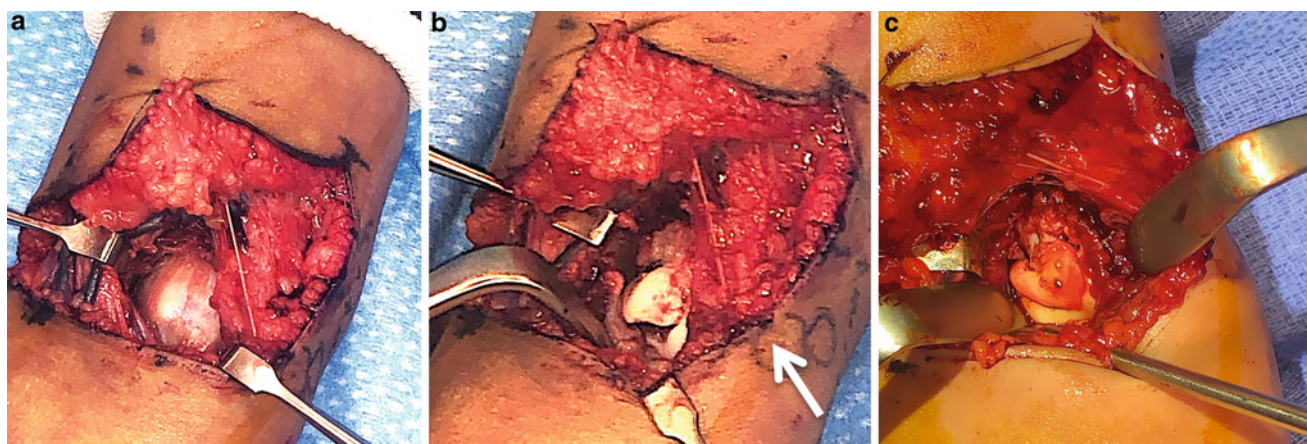


Fig. 4 (a) Anterior approach to the distal humerus with fracture fragment elevating joint capsule. (b) Osteochondral trochlear shear fracture flipped anteriorly with recess at site of coronoid engagement (white

arrow). (c) Anatomic reduction of fragment with Kirschner wire fixation. Kirschner wires buried just deep to chondral surface

- Physicians should maintain an elevated level of suspicion for these types of injuries especially in children where the epiphyses have not yet ossified.
- Three-dimensional imaging via ultrasound, MRI, or an intraoperative arthrogram should be strongly considered in order to better characterize the lesion and plan further treatment.
- There are multiple options for fixation with benefits and drawbacks to each. Physicians should have an understanding of each of the options and utilize the one that allows for adequate fixation while minimizing risk of complications.
- The primary complication with these rare types of injuries is the failure of diagnosis. Once diagnosed, even with appropriate treatment, major complications include nonunion, avascular necrosis, growth arrest, heterotopic ossification, joint contractures, and late joint subluxation (Waters et al. 2010).

Kirschner wires are just deep to the chondral surface. This allows removal of implants without requiring a second sedation.

- Casting of the elbow should oppose chondral surfaces to allow for molding and remodeling of chondral fragment. Range of motion should begin as soon as healing allows in order to further encourage this remodeling and prevent joint contractures.
- Due to deformation of the cartilage fragment during injury and swelling post-injury, the small osteochondral fragment may not fully reduce to the donor site. Shaving down and shaping of the fragment may be required. It is important for the fragment to not lie above the donor site as this can cause instability after motion is initiated.

6 Images During Treatment

7 Technical Pearls

- As these fragments are small and intra-articular, the chosen surgical approach should allow the best visualization of reduction of the fragment and placement of fixation device.
- Kirschner wires can be utilized for fixation by directing them through the fragment into the donor site and then pulling the wire out posteriorly until

8 Avoiding and Managing Problems

- Never assume that a small radiographic osseous fragment is benign. The donor site should be identified. MRI, ultrasound, and CT scans are all options for better characterization of the lesion. If there is a significant block to motion or a larger amount of swelling than would be expected for the fracture seen on radiographs, further investigation is warranted.
- Fixation of these fragments can be challenging. Be prepared with multiple fixation options and choose which one best fits the needs of the fracture once it is visualized intraoperatively (Fig. 5a, b).
- Ensure that families are aware of the risks of nonunion, avascular necrosis, and future elbow stiffness. Understanding the complexity of these fractures and the

Fig. 5 (a, b) Radiographs demonstrating open reduction internal fixation of the osteochondral fragment with multiple K-wire fixation augmented by long arm cast



challenges associated with their treatment is an absolute necessity.

The primary goal in repairing these fractures should be a smooth gliding joint. If a smooth articular surface cannot be obtained due to fragmentation of the fragment, severe deformation, or other complications, the fragment should be excised in order to avoid blocks to motion.

9 Cross-References

- [An Elbow Dislocation with and Without Additional Fractures](#)
- [Capitellar Fractures](#)
- [Medial Condyle Fracture](#)

References and Suggested Readings

- Barfod G, Svendsen RN (1992) Synovitis of the knee after intraarticular fracture fixation with biofix. Report of two cases. *Acta Orthop Scand* 63(6):680–681
- Fridén T, Rydholm U (1992) Severe aseptic synovitis of the knee after biodegradable internal fixation. A case report. *Acta Orthop Scand* 63(1):94–97
- Scioscia TN, Giffin JR, Allen CR, Harner CD (2001) Potential complication of bioabsorbable screw fixation for osteochondritis dissecans of the knee. *Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc* 17(2):E7. <https://doi.org/10.1053/jars.2001.17995>
- Waters PM, Beaty J, Kasser J (2010) Elbow “TRASH” (The radiographic appearance seemed harmless) lesions. *J Pediatr Orthop* 30 (Supp 2):S77–S81

Olecranon Fracture: Tension Band Technique

Cort D. Lawton, Bennet A. Butler, and John J. Grayhack

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Abstract

Pediatric olecranon fractures are rare injuries, generally occurring as a result of indirect trauma. The most common mechanism of injury is a fall onto an outstretched hand, with the elbow in flexion, leading to triceps tensioning and an avulsion-type fracture of the olecranon. While many olecranon fractures may be treated conservatively, most fractures with displacement, those associated with dislocations or elbow instability, as well as open fractures should be managed operatively. Olecranon fractures without comminution or instability may be managed with

tension band wiring, intramedullary screw, or plate fixation. Simple transverse fracture patterns without comminution are ideal for tension band wiring. For this technique, the anterior cortex cannot be comminuted and must provide a buttress to allow for compression. The tension band construct counteracts the tensile forces on the posterior side of the olecranon during elbow flexion and converts these tensile forces into compression forces at the articular surface. This technique remains one of the most popular methods used for fixation of olecranon fractures.

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1 Brief Clinical History

The patient was a 10-year-old male with no significant past medical history who presented with right elbow pain after a bicycle accident. On examination, the fracture was closed and his neurovascular exam was intact. Radiographs were

obtained of the right elbow demonstrating a displaced transverse intra-articular fracture of the olecranon without evidence of comminution (Fig. 1). The patient had no other significant injuries as a result of his accident.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

- Displaced olecranon fracture

4 Treatment Strategy

Given the degree of displacement and inability to achieve adequate articular congruency with attempted closed reduction, the decision was made to proceed with open reduction internal fixation. Fixation options included tension band wiring, intramedullary screw, and plate fixation (Den Hamer et al. 2015). Review of the radiographs demonstrated a simple transverse fracture pattern without evidence of comminution, making this injury ideal for tension band wiring (Corradin et al. 2016). Our plan was to use the standard AO tension band wiring technique with two parallel Kirschner wires (K-wires) and 18-gauge stainless steel wire for the tension band construct.

Fig. 1 Preoperative AP (a) and lateral (b) radiographs of the right elbow demonstrating a displaced transverse fracture of the olecranon without evidence of comminution

5 Basic Principles

The patient may be positioned supine with the arm placed over the chest, lateral with the arm over an arm board, or prone with the arm on an arm table. We prefer the supine position with the arm placed over the chest for simple fracture patterns (Fig. 2a). A standard posterior approach to the proximal ulna was performed. The fracture site was cleaned of hematoma and soft tissue. A pointed reduction clamp was used to maintain reduction of the fracture (Fig. 2b). A smooth K-wire was advanced from the posterior aspect of the olecranon passing just beneath the articular surface and through the anterior cortex distal to coronoid process. A second K-wire was placed in a parallel fashion. A transverse drill hole was then made in the distal segment 3–4 cm distal to the fracture. An 18-gauge stainless steel wire was then passed through the drill hole. The wire was passed deep to the triceps using a 16-gauge angiocatheter in front of and proximal to the K-wires. The wire was then crossed in a figure-of-eight fashion and twisted down tautly to achieve fracture fixation. The twisted wire excess was cut, redirected, and impacted along the radial side of the ulna. The K-wires were bent and advanced to the level of the triceps overlying the tension band. After testing stability of the completed construct, final radiographs were obtained (Fig. 3). Closure was accomplished in standard fashion. A well-padded long-arm cast was applied.

6 Images During Treatment

See Figs. 2 and 3.



Fig. 2 Intraoperative lateral radiographs of the displaced olecranon fracture (**a**) and reduction of the fracture with a pointed reduction clamp (**b**)

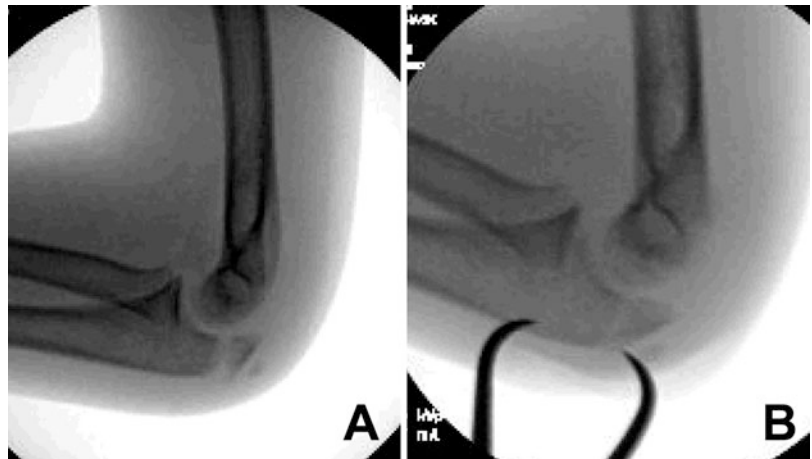
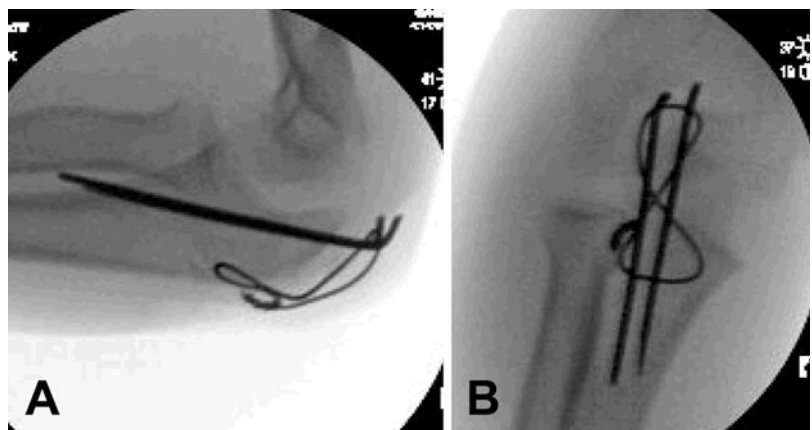


Fig. 3 Intraoperative lateral (**a**) and AP (**b**) radiographs of the final construct



7 Technical Pearls

A sterile tourniquet may be placed on the upper arm to assist with visualization during surgery. The tension band wiring technique is an ideal treatment option for simple transverse fracture patterns without comminution (Chalidis et al. 2008). Comminution discovered intraoperatively may require consideration for alternative fixation techniques such as plate and screw constructs (Den Hamer et al. 2015). A small drill hole may be predrilled 1–2 cm distal to the fracture site to place the reduction clamp and prevent it from slipping on the distal fragment during fracture reduction. After advancement of the K-wires through the anterior cortex, back the K-wires out approximately 1 cm. The proximal ends of the K-wires should be bent and hammered into the bone proximally to prevent hardware prominence, which will result in the distal ends protruding into the anterior soft tissues if the K-wires are not backed out 1 cm as previously mentioned. During tensioning of the wire, ensure that the wire spirals equally to avoid a twist where one wire spirals around a straight wire. Trim the twisted wire and turn the ends toward the ulna to

prevent excessive irritation of the soft tissues. The use of suture for the tension band construct has been reported in an attempt to limit the incidence of symptomatic hardware; however, suture tension bands have lower ultimate failure loads and result in less compression at the fracture site (Parent et al. 2008). Confirm fracture stability and range of motion, including supination and pronation prior to leaving the operating room as K-wires may impinge on the radius.

8 Outcome Clinical Photos and Radiographs

See Figs. 4 and 5.

9 Avoiding and Managing Problems

Symptomatic hardware can be common with this technique, in part due to the subcutaneous nature of the proximal ulna. Refer to Sect. 7 for ways to limit hardware

Fig. 4 Two-week postoperative AP (a) and lateral (b) radiographs showing maintained fracture reduction

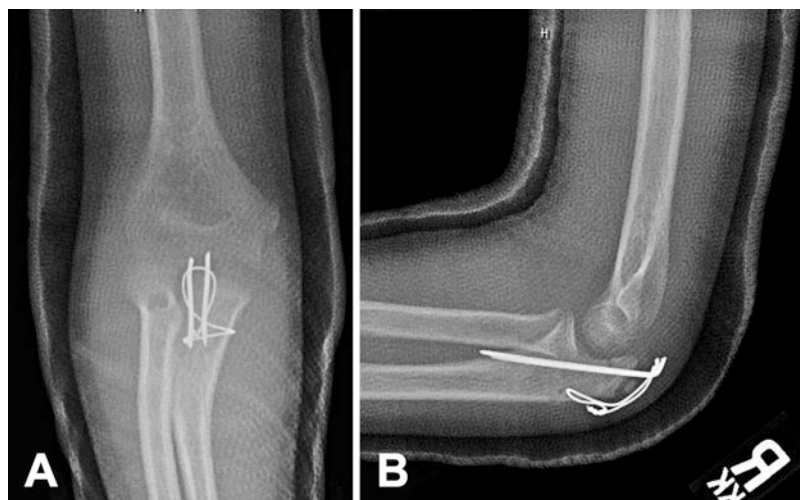
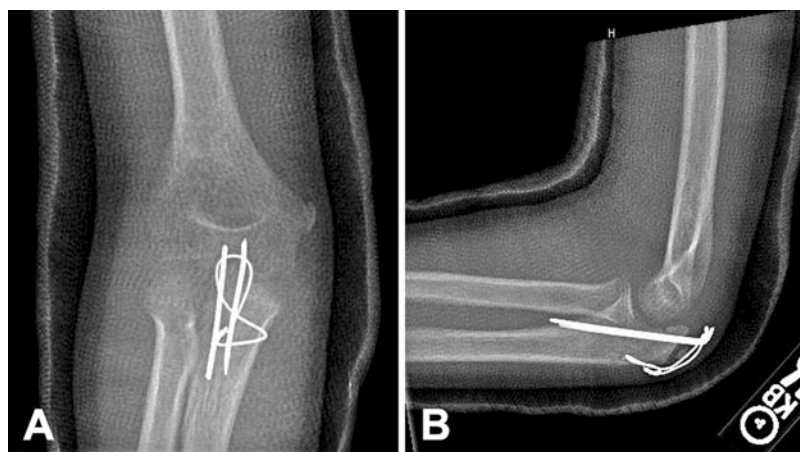


Fig. 5 One-month postoperative AP (a) and lateral (b) radiographs demonstrating interval healing at the fracture site



prominence. To avoid long-term elbow stiffness, passive range of motion exercises should be started as soon as possible after surgery. To prevent loss of reduction and subsequent malunion or nonunion, it is important to test stability of your construct prior to leaving the operating room.

10 Cross-References

- Olecranon Fracture: Intramedullary Screw
- Olecranon Fracture: Plating Technique
- Olecranon Fractures: Apophysis Osteogenesis Imperfecta

References and Suggested Readings

- Chalidis BE, Sachinis NC, Samoladas EP, Dimitriou CG, Pournaras JD (2008) Is tension band wiring technique the “gold standard” for the treatment of olecranon fractures? A long term functional outcome study. *J Orthop Surg Res* 3:9
- Corradin M, Marengo L, Andreacchio A, Paonessa M, Giacometti V, Samba A, Rousset M, Federico C (2016) Outcome of isolated olecranon fractures in skeletally immature patients: comparison of open reduction and tension band wiring fixation versus closed reduction and percutaneous screw fixation. *Eur J Orthop Surg Traumatol* 26:469–476
- Den Hamer A, Heusinkveld M, Traa W, Oomen P, Oliva F, Del Buono A, Maffulli N (2015) Current techniques for management of transverse displaced olecranon fractures. *Muscles Ligaments Tendons J* 5:129–140
- Parent S, Wedemeyer M, Mahar AT, Anderson M, Fargo F, Steinman S, Lalonde F, Newton P (2008) Displaced olecranon fractures in children: a biomechanical analysis of fixation methods. *J Pediatr Orthop* 28:147–151

Olecranon Fracture: Plating Technique

Bennet A. Butler, Cort D. Lawton, and John J. Grayhack

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Abstract

Olecranon fractures in the pediatric population are uncommon injuries. A majority of displaced fractures, fractures associated with elbow dislocations or instability, and open fractures should be managed operatively. Common constructs used for olecranon fractures include tension band wiring, intramedullary screw, or plate fixation. Comminuted olecranon fractures are frequently a result of direct trauma. Plate and screw constructs are generally recommended for these injuries. The

primary goal of surgery is restoration of the articular surface.

1 Brief Clinical History

The patient was a 13-year-old male with no past medial history who presented with left elbow pain after a snowmobiling accident. On examination, there were no open wounds, and the patient was neurovascularly intact to his left upper extremity. Radiographs were obtained of the left elbow demonstrating a displaced fracture of the olecranon with evidence of comminution (Fig. 1). The patient had no other significant injuries from his accident.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

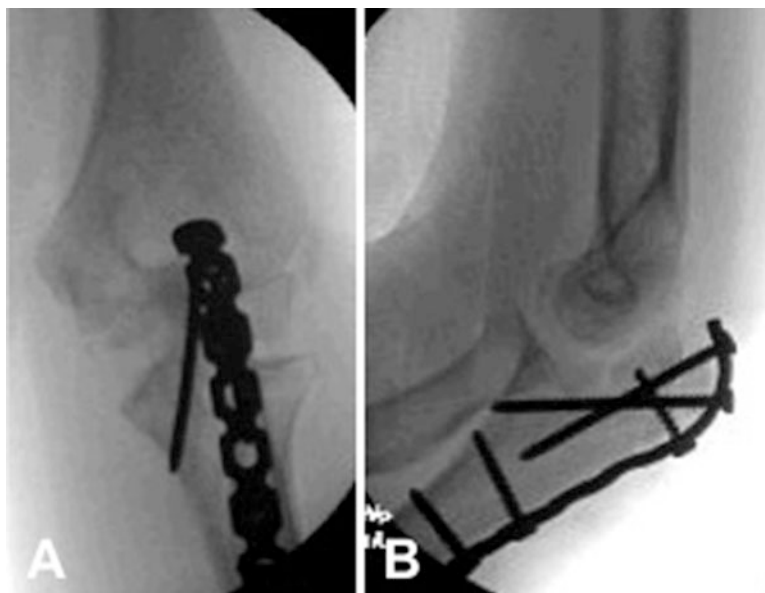
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Fig. 1 Preoperative AP (a) and lateral (b) radiographs of the left elbow demonstrating a displaced fracture of the olecranon with evidence of comminution



Fig. 2 Intraoperative AP (a) and lateral (b) radiographs of the final construct



3 Preoperative Problem List

1. Displaced comminuted olecranon fracture

4 Treatment Strategy

Given the intra-articular displacement and comminution, the decision was made to proceed with operative intervention. Common fixation constructs for olecranon fractures include tension band, intramedullary screw, and plate fixation (Den Hamer et al. 2015). Dorsal plating is ideal for comminuted fractures, as well fractures associated with instability (Kloen and Buijze 2009). Our plan was for dorsal plating of this fracture in an effort to

provide optimal support to the area of articular comminution, while avoiding over compression of the comminuted segment.

5 Basic Principles

We positioned the patient supine with the arm draped over an armrest, which is our preferred positioning for more complex fracture patterns (Fig. 1). A standard subcutaneous posterior approach to the proximal ulna was used. The fracture site was cleared of soft tissue and hematoma. The fracture was booked open, the comminuted pieces were reduced, and preliminary reduction was held with K-wires. A pointed reduction clamp was used to hold reduction of the larger fragments and provide compression. A 7-hole reconstruction plate was

Fig. 3 Two-week postoperative AP (a) and lateral (b) radiographs showing maintained fracture reduction

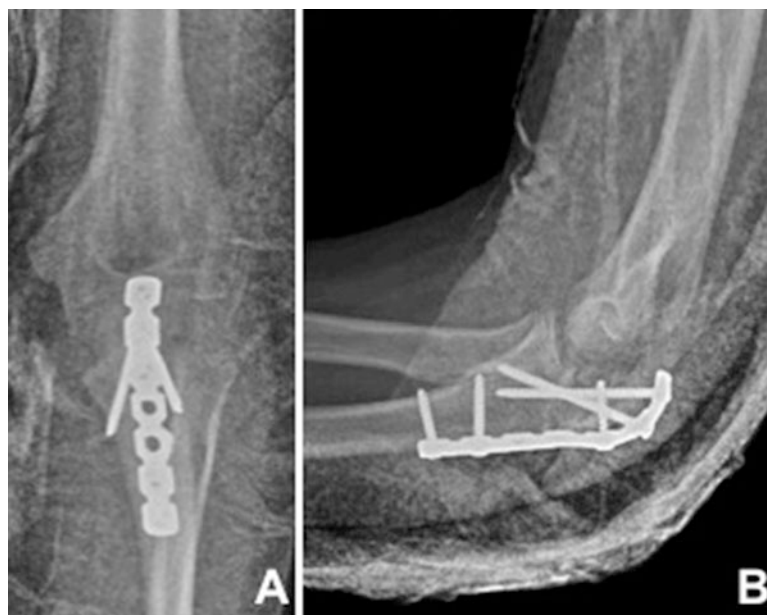


Fig. 4 Six-week postoperative AP (a) and lateral (b) radiographs demonstrating interval healing at the fracture site



chosen. Three proximal and two distal 4.0 cancellous screws were used for fixation. The second most proximal screw was placed just beneath the articular surface to prevent subsidence of the articular surface. Fluoroscopy was used to confirm no screws violated the articular surface. After testing stability of the final construct, final radiographs were obtained (Fig. 2). Closure was accomplished in standard fashion. A well-padded long-arm splint was applied.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

A sterile tourniquet may be placed to assist with visualization during surgery. For more complex fracture patterns, we prefer lateral or prone positioning to allow for fluoroscopic imaging without significant manipulation of the arm. If articular comminution or impaction is present, the fracture may be booked open to allow for anatomic reduction of the articular surface. Effort should be made to preserve comminuted articular fragments. K-wires may be used to hold a preliminary reduction. Once the articular surface is reduced, the larger fragments may be compressed with a pointed reduction clamp. A small hole

Fig. 5 Four-month postoperative AP (a) and lateral (b) radiographs demonstrating a healed olecranon fracture without evidence of hardware failure



may be drilled 1–2 cm distal to the fracture site to improve purchase of the pointed reduction clamp in the distal segment. Plate options include reconstruction plates, 1/3 tubular plates, or pre-contoured anatomic plates for larger children. When necessary, inter-fragmentary lag screws may be placed outside of the plate. Long locking or non-locking position screws should be placed proximal to distal just beneath the articular surface to offer support to any comminuted fragments. Fluoroscopy should be used to ensure no screws violate the articular surface prior to closure. When possible, the fascia should be closed over the plate to decrease plate irritation. Confirm fracture stability prior to leaving the operating room.

8 Outcome Clinical Photos and Radiographs

See Figs. 3, 4, and 5.

9 Avoiding and Managing Problems

Obtaining high-quality fluoroscopic imaging intraoperatively is important to ensure there is no intra-articular screw penetration. Symptomatic hardware can be common with fixation of

olecranon fractures. Placing the plate more laterally and closing fascia over the plate are two ways to limit plate prominence. To limit long-term elbow stiffness, passive range of motion exercises should be started as soon as possible after surgery. Nonunion is rarely encountered given the good blood supply about the elbow. Nonunions can be treated with revision open reduction internal fixation with or without bone grafting.

10 Cross-References

- [Olecranon Fracture: Intramedullary Screw](#)
- [Olecranon Fracture: Tension Band Technique](#)
- [Olecranon Fractures: Apophysis Osteogenesis Imperfecta](#)

References and Suggested Readings

- Den Hamer A, Heusinkveld M, Traa W, Oomen P, Oliva F, Del Buono A, Maffulli N (2015) Current techniques for management of transverse displaced olecranon fractures. *Muscles Ligaments Tendons J* 5:129–140
- Kloen P, Buijze GA (2009) Treatment of proximal ulna and olecranon fractures by dorsal plating. *Oper Orthop Traumatol* 21(6):571–585

Olecranon Fracture: Intramedullary Screw

Cort D. Lawton, Bennet A. Butler, and John J. Grayhack

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Abstract

Olecranon fractures are uncommon injuries in the pediatric population. A majority of displaced fractures, those associated with dislocations or elbow instability, and open fractures should be managed operatively. Tension band wiring, intramedullary screw, and plate fixation are the most common constructs used for olecranon fractures. For transverse fracture patterns without comminution, intramedullary screw fixation with a supplemental suture tension band provides increased compression across the fracture site while limiting hardware prominence when

compared to the traditional tension band wiring technique. This technique is an excellent option for patients where symptomatic hardware is a concern.

1 Brief Clinical History

The patient was a 12-year-old male with a past medical history of osteogenesis imperfecta and multiple previous fractures, including a previous well-healed left olecranon fracture, who presented with left elbow pain after a fall. His previous left olecranon fracture was fixed with a tension band construct and was complicated by symptomatic hardware. As a result, he subsequently underwent removal of hardware. On examination, the fracture was closed and the patient was neurovascularly intact to his left upper extremity. Radiographs were obtained of the left elbow demonstrating a displaced transverse intra-articular fracture of the olecranon without evidence of comminution (Fig. 1).

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2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Displaced olecranon fracture

4 Treatment Strategy

Given the degree of displacement, the patient was taken to the operating room for an open reduction with internal fixation. Options for surgical fixation included tension band wiring, intramedullary screw, and plate fixation (Den Hamer et al. 2015). After fixation of the patient's previous olecranon fracture, he experienced symptomatic hardware requiring hardware removal. We therefore decided to avoid tension band wiring. Review of the radiographs demonstrated a simple transverse fracture pattern without evidence of comminution. The operative plan was for intramedullary screw fixation with a supplemental suture tension band to limit hardware prominence. Fixation of olecranon fractures using an intramedullary screw combined with a tension band has been shown to have equivalent outcomes to the traditional tension band wiring technique, with the benefit of lower removal of hardware rates (Ahmed et al. 2008). Furthermore, this construct provides strength of fixation by converting the tensile forces to compressive forces at the fracture site through the tension band, with additional fracture

compression provided by the intramedullary screw (Raju and Gaddagi 2013).

5 Basic Principles

We positioned the patient supine with the arm placed over the chest, which is our preferred positioning for simple fracture patterns (Fig. 1). A standard posterior approach to the proximal ulna was performed through the patient's previous incision. The fracture site was cleaned of soft tissue and hematoma. Reduction of the fracture was achieved with a pointed reduction clamp (Fig. 2a). A guide wire was advanced from the posterior aspect of the olecranon passing across the fracture site to the anterior cortex of the ulna just distal to the coronoid (Fig. 2b). The wire was measured, and a 55 mm cancellous screw was selected. A 2.7 mm drill was used to drill along the length of the wire, followed by over drilling of the proximal fracture fragment. The guide wire was removed, and a 55 mm 4.0 mm fully threaded cancellous screw over a washer was placed in compression mode. Prior to final seating of the screw, a transverse drill hole was made 1 cm distal to the fracture line. A suture passer was used to pass FiberWire suture through the drill hole, which was then tied in a figure-of-eight fashion around the neck of the screw. After tying the FiberWire, the screw was tightened and the clamp was removed. Intraoperative fluoroscopy was used to confirm reduction and stability at the fracture site (Fig. 3).

6 Images During Treatment

See Figs. 2 and 3.

Fig. 1 Preoperative AP (a) and lateral (b) radiographs of the left elbow demonstrating a displaced transverse fracture of the olecranon without evidence of comminution



Fig. 2 Intraoperative lateral radiographs of the fracture reduction with a pointed reduction clamp (a) and insertion of the guide wire (b)

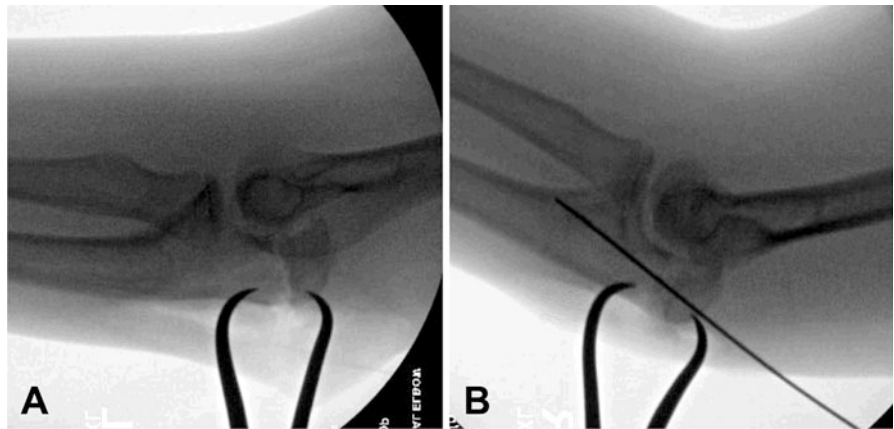


Fig. 3 Intraoperative AP (a) and lateral (b) radiographs of the final construct



7 Technical Pearls

A sterile tourniquet may be used to assist with visualization during surgery. To prevent the reduction clamp from slipping on the distal fragment, a small drill hole may be predrilled 1–2 cm distal to the fracture site for placement of the reduction clamp. It should be noted that the use of suture tension bands in the traditional tension band technique has lower ultimate failure loads and less compression at the fracture site when compared to the use of wire for the tension band construct (Parent et al. 2008). However, using an intramedullary screw technique, compression at the fracture site is generated with the compression screw, and an adjunctive suture tension band can provide added stability while limiting hardware prominence (Raju and Gaddagi 2013). The use of a washer helps prevent the screw from migrating through the cartilage tip in the skeletally immature patient.

8 Outcome Clinical Photos and Radiographs

See Figs. 4 and 5.

9 Avoiding and Managing Problems

Symptomatic hardware is a common complication after fixation of olecranon fractures, in part due to the subcutaneous nature of the proximal ulna. Use of an intramedullary screw supplemented with a suture tension band can limit hardware prominence over other fixation techniques. It is important to understand the anatomical bowing of the proximal ulna and to confirm adequate placement of the guide wire prior to drilling. This will help prevent the screw from being redirected, which may result in loss

Fig. 4 One-week postoperative AP (a) and lateral (b) radiographs showing maintained fracture reduction

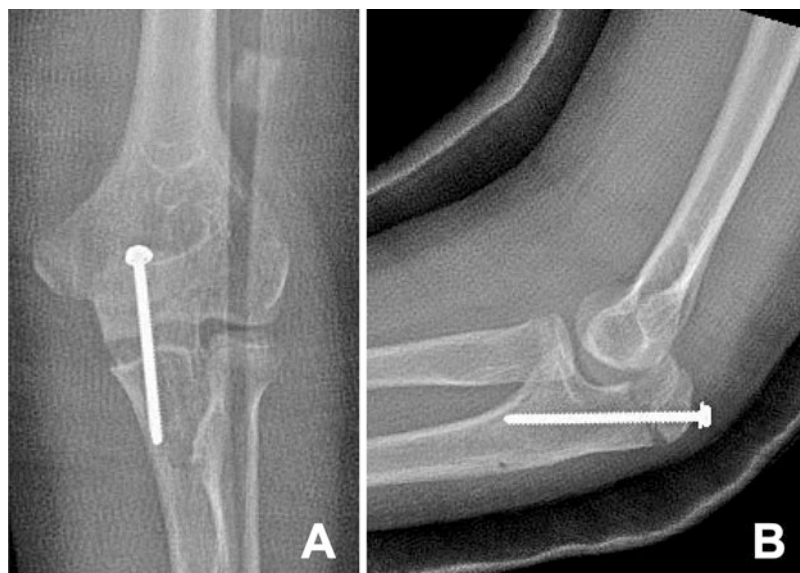


Fig. 5 Two-month postoperative AP (a) and lateral (b) radiographs demonstrating a well-healed fracture with no evidence of hardware failure



of fracture reduction. Passive range of motion exercises should be started as soon as possible after surgery to avoid long-term elbow stiffness. Testing stability of the final construct will prevent loss of reduction and subsequent malunion or nonunion from inadequate fracture stability.

► **Editors' Tips and Pearls** This case illustrates fixation with a 4.0 mm screw and washer, supplemented by a tension band. For simple fracture patterns, fracture compression can often be achieved with a screw construct. Depending on the size of the patient and the intramedullary canal, screw size may be up to 7.0 mm. If excellent purchase is not gained in the medullary canal with a partially

threaded compression screw, the construct can be augmented with a tension band. Another alternative is to switch to a smaller cortical screw and change the trajectory with a slight angle to gain purchase in the cortex of the ulna either medially or laterally on the distal side of the fracture.

10 Cross-References

- [Olecranon Fracture: Plating Technique](#)
- [Olecranon Fracture: Tension Band Technique](#)
- [Olecranon Fractures: Apophysis Osteogenesis Imperfecta](#)

References and Suggested Readings

- Ahmed AR, Sweed T, Wanas A (2008) The role of cancellous screw with tension band fixation in the treatment of displaced olecranon fractures, a comparative study. *Eur J Orthop Surg Traumatol* 18:571–576
- Den Hamer A, Heusinkveld M, Traa W, Oomen P, Oliva F, Del Buono A, Maffulli N (2015) Current techniques for management of transverse displaced olecranon fractures. *Muscles Ligaments Tendons J* 5:129–140
- Parent S, Wedemeyer M, Mahar AT, Anderson M, Fargo F, Steinman S, Lalonde F, Newton P (2008) Displaced olecranon fractures in children: a biomechanical analysis of fixation methods. *J Pediatr Orthop* 28:147–151
- Raju SM, Gaddagi RA (2013) Cancellous screw with tension band wiring for fractures of the olecranon. *J Clin Diagn Res* 7(2):339–341

Olecranon Fractures: Apophysis Osteogenesis Imperfecta

Bennet A. Butler, Cort D. Lawton, and John J. Grayhack

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Abstract

Osteogenesis imperfecta is a condition characterized by skeletal fragility due to mutations in the genes for the type I collagen components (COL1A1 and COL1A2). Olecranon fractures are especially common in osteogenesis imperfecta. Apophyseal avulsion fractures of the olecranon, in particular, are considered essentially pathognomonic of the condition. Because children with osteogenesis imperfecta tend to exhibit normal healing responses to skeletal trauma, these injuries are treated with similar techniques as those used for unaffected

children. Displaced fractures generally require operative intervention with tension band wiring, intramedullary screw, or plate fixation. The use of a modified tension band technique utilizing percutaneous axial K-wires and suture tension band avoids the need for reoperation for symptomatic hardware. Postoperatively, patients with osteogenesis imperfecta should be referred to a geneticist and/or skeletal dysplasia clinic for long-term care. Some of these patients benefit from medical management with bisphosphonates, which have been shown to decrease chronic skeletal pain and future fracture risk.

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1 Brief Clinical History

The patient was a 12-year-old male with a past medical history of osteogenesis imperfect and multiple previous fractures, including a previous well-healed right olecranon fracture, and aortic stenosis who presented with right elbow pain after a fall. His previous right olecranon fracture was fixed with a tension band wiring construct and was complicated by symptomatic hardware. As a result, he subsequently

Fig. 1 Preoperative AP (a) and lateral (b) radiographs of the right elbow demonstrating a displaced avulsion fracture of the olecranon without evidence of comminution



underwent removal of hardware. Upon presentation, the fracture was closed and the neurovascular exam was intact. Radiographs were obtained of the right elbow demonstrating a displaced avulsion fracture of the olecranon without evidence of comminution (Fig. 1). After evaluation by the cardiology service for his aortic stenosis, the patient was cleared for operative intervention.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Displaced olecranon avulsion fracture
2. Osteogenesis imperfecta
3. Aortic stenosis

4 Treatment Strategy

Given the degree of displacement, the patient was taken to the operating room for operative intervention. Options for surgical fixation for avulsion-type olecranon fractures include tension band wiring and intramedullary screw fixation (Den Hamer et al. 2015). Tension band constructs are widely accepted as the primary treatment choice for transverse fractures of the olecranon (Karlsson et al. 2002). Fixation of his previous olecranon fracture was complicated by symptomatic hardware requiring

hardware removal. Our plan was for a modified tension band construct with removable percutaneous axial K-wires and a suture tension band to avoid the need for reoperation for symptomatic hardware, which is a common complication of the traditional AO tension band wiring technique.

5 Basic Principles

We positioned the patient supine with his arm placed over his chest, which is our preferred positioning for simple fracture patterns (Fig. 1). A standard posterior approach to the proximal ulna was performed through the patient's previous incision. The fracture site was cleaned of soft tissue and hematoma. Fracture reduction was maintained with a pointed reduction clamp. A transverse tunnel was drilled through the distal segment, and a suture passer was used to pass FiberWire through the bone tunnel. Two percutaneous K-wires were advanced from the posterior aspect of the olecranon, just beneath the articular surface, and into the ulnar diaphysis in a parallel fashion. The FiberWire was then used to create a figure-of-eight tension band construct. After testing fracture stability, final radiographs were obtained (Fig. 2). Closure was accomplished in standard fashion. A well-padded long-arm cast was applied. The K-wires were removed in clinic at his 4-week follow-up, and he was transitioned into a hinged elbow brace for an additional 2 weeks.

6 Images During Treatment

See Fig. 2.

Fig. 2 Intraoperative AP (a) and lateral (b) radiographs of the final tension band construct

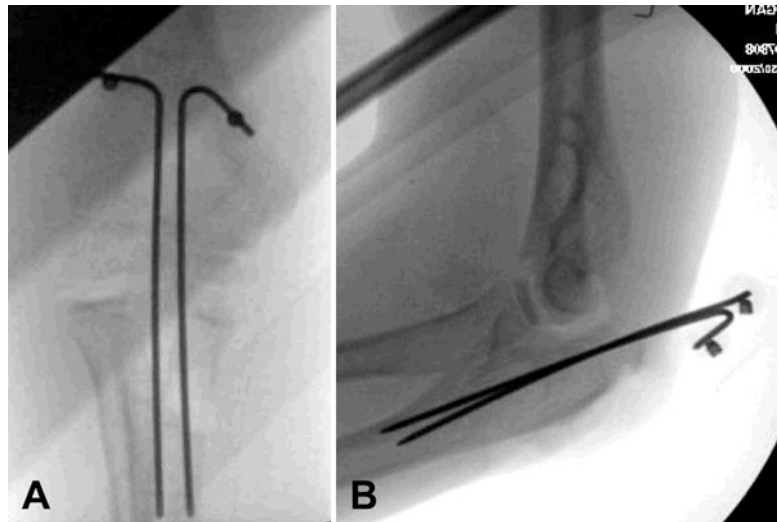


Fig. 3 One-week postoperative AP (a) and lateral (b) radiographs showing maintained fracture reduction

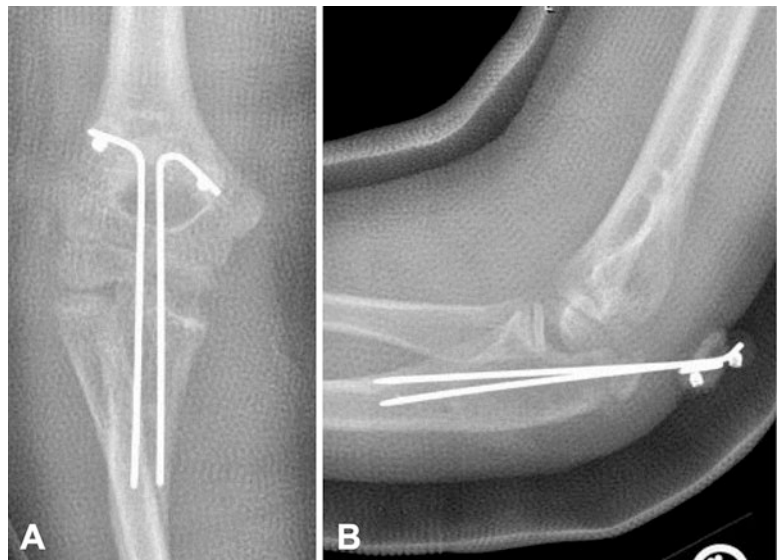


Fig. 4 One-month postoperative AP (a) and lateral (b) radiographs demonstrating interval healing at the fracture site

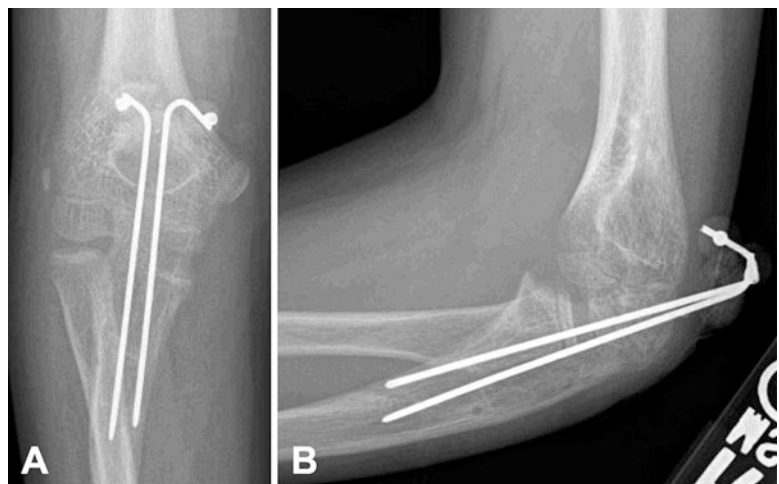


Fig. 5 Four-month postoperative AP (a) and lateral (b) radiographs demonstrating a healed avulsion fracture with interval removal of the percutaneous K-wires



7 Technical Pearls

A sterile tourniquet may be used to assist with visualization during surgery. A small drill hole may be predrilled 1–2 cm distal to the fracture site to place the reduction clamp and prevent it from slipping on the distal fragment during fixation. Confirm fracture stability prior to leaving the operating room. The traditional tension band wiring technique is widely accepted as the primary treatment choice for transverse fractures of the olecranon in children (Karlsson et al. 2002). A common complication of this technique is symptomatic hardware (Den Hamer et al. 2015). A modified tension band construct with removable percutaneous axial K-wires and a suture tension band has been described, with the benefit of avoiding reoperation for symptomatic hardware (Gortzak et al. 2006). However, suture tension bands have been shown to have lower ultimate failure loads and result in less compression at the fracture site (Parent et al. 2008). Therefore, we recommend a period of cast immobilization postoperatively, with consideration for transition to a hinged elbow brace for added protection of the tension band construct.

8 Outcome Clinical Photos and Radiographs

See Figs. 3, 4, and 5.

9 Avoiding and Managing Problems

Symptomatic hardware can be a common complication with traditional tension band wiring techniques; however, the technique used in this case avoids the requirement for

reoperation for symptomatic hardware. To avoid long-term elbow stiffness, passive range of motion exercises should be started as soon as possible after surgery. To prevent loss of reduction and subsequent malunion or nonunion, it is important to test fracture stability after completion of the final construct. Patients with osteogenesis imperfecta presenting with a fracture should be referred to a geneticist and/or skeletal dysplasia clinic for medical management. Medications such as bisphosphonates have been shown to decrease chronic skeletal pain and future fracture risk.

10 Cross-References

- [Olecranon Fracture: Intramedullary Screw](#)
- [Olecranon Fracture: Plating Technique](#)
- [Olecranon Fracture: Tension Band Technique](#)

References and Suggested Readings

- Den Hamer A, Heusinkveld M, Traa W, Oomen P, Oliva F, Del Buono A, Maffulli N (2015) Current techniques for management of transverse displaced olecranon fractures. *Muscles Ligaments Tendons J* 5:129–140
- Gortzak Y, Mercado E, Atar D, Weisel Y (2006) Pediatric olecranon fractures open reduction and internal fixation with removable Kirschner wires and absorbable sutures. *J Pediatr Orthop* 26:39–42
- Karlsson MK, Hasselius R, Karlsson C, Besjakov J, Josefsson PO (2002) Fractures of the olecranon during growth: a 15- to 25-year follow-up. *J Pediatr Orthop* 11:251–225
- Parent S, Wedemeyer M, Mahar AT, Anderson M, Fargo F, Steinman S, Lalonde F, Newton P (2008) Displaced olecranon fractures in children: a biomechanical analysis of fixation methods. *J Pediatr Orthop* 28:147–151

Type I Monteggia Fractures

Tyler J. Stavinocha

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Abstract

Type I Monteggia fractures are defined as proximal ulna fracture with associated anterior dislocation of the radial head (Bae, *J Pediatr Orthop*, 36:S67–S70, 2016; Bado, *Clin Orthop Relat Res*, 50(1):71–86, 1967). These injuries make up the most common Monteggia fracture type in children, but often require high clinical suspicion to prevent missed diagnosis (Monteggia, *Instituzioni chirurgiche*, 5:131–133, 1814). Irregular and incomplete ossification of the skeletally immature elbow limits the accurate interpretation of static radiographs. While some controversy exists as to which fracture patterns warrant surgical stabilization, operative options include elastic stable intramedullary nailing (ESIN) or open reduction and internal fixation of the ulna with secondary reduction

of the radiocapitellar joint. For severe injuries, additional open reduction of the radiocapitellar joint may be necessary.

1 Brief Clinical History

The patient is an 8-year-old male who fell from the monkey bars onto an outstretched hand and sustained an isolated injury to his right elbow. He presented initially to an outside facility and was splinted prior to transfer to our tertiary referral center for higher-level care.

He had a type I open injury, with a 5 mm wound on the volar aspect of his forearm. He was neurovascularly intact throughout the distal extremity and was noted to have palpable radial and ulnar pulses and well-perfused fingertips. He demonstrated intact distal motor function throughout AIN, PIN, median, and ulnar nerve-innervated musculature. Sensation was initially noted to be diminished in the median nerve distribution but intact throughout the radial and ulnar distributions.

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Fig. 1 (a–d) Initial injury radiographs (a–c) demonstrate anterior displacement of the radial head of a Bado type I Monteggia fracture. Postreduction splinted radiograph (d) shows residual anterior subluxation of the radiocapitellar joint

Radiographs of the elbow and forearm were obtained and demonstrated a type I Monteggia fracture dislocation with displaced, short oblique fracture pattern of the ulna. Further evaluation of the forearm and humerus films showed no other fractures.

On arrival, the patient received tetanus booster and first-generation cephalosporin antibiotic dosing. The volar wound was irrigated thoroughly with sterile saline lavage. A closed reduction was performed in the emergency department with ketamine sedation monitored by an emergency medicine physician. A single attempt was made and showed residual anterior subluxation of the radial head with an incongruent radiocapitellar joint. The splint was placed in less than 90° flexion, which may have improved radiocapitellar alignment. Recommendations and plans for operative intervention were discussed with the parents, and the patient was admitted overnight with close compartment and neurovascular monitoring.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Right elbow Monteggia fracture dislocation, anterior, type 1
2. Type 1 open fracture
3. Median nerve sensory neuropraxia

4 Treatment Strategy

Though Monteggia fractures are rare, making up 1–2% of pediatric forearm injuries, a high clinical suspicion is imperative to prevent missed injury or delayed diagnosis.

Radiographic parameters that assess that radiocapitellar joint for dislocation also guide both intraoperative reduction assessment and close radiographic follow-up. The primary aim is to ensure appropriate reduction of the radiocapitellar joint to ensure appropriate elbow joint stability (Bae 2016; Bado 1967; Monteggia 1814). Orthopedic surgeons should make a habit of “drawing the radiocapitellar line” visually every time a child’s elbow or forearm radiograph is viewed to avoid missing Monteggia injuries.

The radiocapitellar line (RCL) must be evaluated to show bisection through the central capitellar ossification center, especially on the lateral radiograph. Evaluation on AP radiographs is less reliable as it has been shown to often more laterally intersect the capitellar ossification center, with evidence that the RCL most often is in the lateral third (Souder et al. 2017; Ramirez et al. 2014; Kunkel et al. 2011) or may miss the capitellar ossification completely (Ramirez et al. 2014; Silberstein et al. 1979) in younger patients. In instances of Bado type I Monteggia fractures where the radial head moves anterior relative to the capitellum (Bado 1967), coronal views are often difficult to assess displacement.

The ulna must be carefully evaluated for displacement, plastic deformities, and fracture pattern stability, all of which may guide initial treatment decisions. Nondisplaced and greenstick fractures often show good clinical outcomes with closed reduction and casting. Stable, displaced fractures, such as transverse and short oblique fractures, may be amenable to ESIN, while long oblique and comminuted fractures may be treated with open reduction and plate fixation. Ring and Waters (1996) introduced this ulnar-based strategy based on the ulnar-based classification introduced by Letts (Letts et al. 1985). This decision algorithm was evaluated by Ramski et al. (2015) in a multicenter series of 112 patients. They found 0% failure following equivalent or more rigorous surgical criteria, compared with 19% loss of reduction in patients treated less aggressively. Alternatively, Foran et al. (2017) retrospectively reviewed 94 patients, all initially treated with closed reduction under sedation in the emergency department. They found an 85% success rate, and no difference noted between length-stable (75% success) and length-unstable (79% success). They emphasized the need for close, weekly follow-up for 3 weeks to identify redisplacement and identified ulnar angulation greater than 36.5° as a predictor of needing surgical stabilization. Of their cohort, 16 (17%) ultimately received surgical intervention, but they determined that 46 more patients would have undergone surgery had they followed a strict ulnar-based strategy. This was somewhat improved from historical literature that cites redislocation at a rate of approximately 20% with closed reduction (Dormans and Rang 1990; Fowles et al. 1983).

Closed reduction of type I fractures may be optimized with reduction maneuvers of longitudinal traction, supination, elbow hyperflexion, and direct pressure on the radial head. Cast

molding may require careful attention to ulnar bowing, seen on the lateral view, which is indicative of subtle plastic deformation. Molding principles for type I Monteggia fractures include attention to counteract the anterior ulnar bowing. It is recommended to follow closed reduction with radiographic assessment weekly for 3 weeks to identify early displacement (Foran et al. 2017).

When surgical fixation is indicated, ulnar fixation is approached first, as restoration of ulnar length most often drives reduction of the radiocapitellar joint (Ho and Turner 2019). A principle is that closed reduction should be able to reduce the radiocapitellar joint, and if the radial head is able to be reduced closed, the ulnar fixation will maintain the reduction. Thus, in the operating room a closed reduction of the radial head dislocation should be attempted first. If the radial head is not reducible closed, then an open reduction of the radiocapitellar joint is needed using either a Kocher or Kaplan approach. If the radial head is reducible, then elastic stable intramedullary nailing affords minimal exposure to maintain reduction for most non-comminuted ulnar fracture patterns. Principles include appropriate starting point opening to and nail size optimization for both passage in the limited intramedullary canal of the ulna, as well as stability to maintain reduction. Alternatively, open reduction and internal plate fixation of the ulna may be necessary to ensure maximal stability if the fracture is comminuted or there is substantial ulnar bowing that needs to be corrected. On rare occasions of the acute Monteggia fracture, radiocapitellar joint stabilization with transarticular pin fixation may be used, if needed. In these cases the author recommends to place a 2 mm K-wire from posterior across the capitellum to anterior across the reduced joint into the radial epiphysis.

5 Basic Principles

1. High clinical suspicion to prevent missed diagnosis, which is reported in up to a third of cases.
2. Early postoperative radiographic monitoring for at least 3 weeks following successful closed reduction.
3. Consider internal fixation for length-unstable ulnar fracture patterns or those with substantial bowing that cannot be reduced with closed techniques.
4. Establish ulnar length and alignment primarily to prevent unnecessary radiocapitellar joint malalignment.
5. Adjunct mini-open reduction assistance to facilitate nail passage when necessary to prevent surrounding soft tissue damage with multiple attempts at nail passage.
6. Severe cases may require open reduction of the radiocapitellar joint, approached through a modified Kocher or Kaplan exposure. Radiocapitellar joint pinning may be considered in severe cases that demonstrate persistent instability.

Fig. 2 (a–d) Intraoperative imaging demonstrates initial ESIN starting point drilling using a 3.2 mm drill bit and tissue protector at the proximal posterolateral olecranon cortex (**a**). Mini-open reduction was performed through the open fracture site following irrigation of the open fracture site (**b**). Final radiographs (**c, d**) demonstrate radiocapitellar reduction with intramedullary stabilization of the ulnar fracture using a 2.5 mm flexible nail



7. Surgical intervention primarily aims to restore radiocapitellar joint stability with bone healing to promote joint motion. To allow for healing of disrupted ligaments and joint capsule of the radiocapitellar joint, the elbow is typically immobilized for 4 weeks after surgical fixation.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

1. Reduce type I Monteggia fractures with longitudinal traction, supination, and elbow hyperflexion while palpating displaced radial head.
2. Reduction often performed in ED with conscious sedation with emergency medicine physician support.
3. Close weekly radiographic monitoring of the radius alignment with the capitellum.
4. Attain ulnar length and alignment to facilitate secondary radiocapitellar joint stability.
5. Limit attempts at blind ESIN passage across the fracture line, as iatrogenic trauma to the surrounding tissues may increase likelihood of compartment syndrome.
6. A starting point at the tip of the olecranon may facilitate a more direct and straight access to the ulnar intramedullary space. In this technique, we routinely cut the curved tip of the flexible nail to enable straight passage and enable larger diameter nail to be passed. Prominence of the tip of the implant may cause patient discomfort or soft tissue irritation resulting early implant removal
7. To counteract plastic deforming forces of the ulna, an apex posterior bend can be placed in the implant, either intramedullary nail or plate.
8. In severe cases in which soft tissue interposition prevents adequate reduction, the radiocapitellar joint can be opened by the interval between the anconeus and ECU (Kocher) or by splitting the muscle fibers of the common extensors (Kaplan).

Fig. 3 (a, b) Four-month postoperative radiographs showing bridging callus formation at the ulna with maintained reduction of the radiocapitellar joint. The patient had full elbow flexion-extension, full pronation and mildly limited supination at this visit. The arc of pronation-supination will improve for 6–12 months after cast removal



8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

1. High clinical suspicion to prevent missed diagnosis.
2. Closely monitor compartment pressures, and consider prophylactic limited forearm fasciotomy when extensive soft tissue dissection is needed for reduction
3. When performing closed reduction, maintain positioning with careful molding to counteract plastic deforming forces or displacement of the ulna.

4. ESIN minimizes soft tissue dissection and can be removed following complete fracture healing to avoid long-term retained hardware.
5. ESIN entry point can be opened with an awl or a drill bit. Slight oblique drilling or wallowing can assist with nail passage.
6. Prevent hardware prominence while cutting ESIN deep to the skin.
7. Maximize nail size to maintain stiffness while still ensuring passage through the intramedullary space.

10 Cross-References

- [Type III Monteggia Fractures](#)

References and Suggested Reading

- Bado JL (1967) The Monteggia lesion. *Clin Orthop Relat Res* 50(1):71–86
- Bae DS (2016) Successful strategies for managing Monteggia injuries. *J Pediatr Orthop* 36:S67–S70
- Dormans JP, Rang M (1990) The problem of Monteggia fracture-dislocations in children. *Orthop Clin North Am* 21(2):251–256
- Foran I, Upasani VV, Wallace CD, Britt E, Bastrom TP, Bomar JD, Pennock AT (2017) Acute pediatric Monteggia fractures: a conservative approach to stabilization. *J Pediatr Orthop* 37(6):e335–e341
- Fowles JV, Sliman N, Kassab MT (1983) The Monteggia lesion in children. Fracture of the ulna and dislocation of the radial head. *J Bone Joint Surg Am* 65(9):1276–1282
- Kunkel S, Cornwall R, Little K, Jain V, Mehlman C, Tamai J (2011) Limitations of the radiocapitellar line for assessment of pediatric elbow radiographs. *J Pediatr Orthop* 31(6):628–632
- Letts M, Lochter RA, Wiens JO (1985) Monteggia fracture-dislocations in children. *J Bone Joint Surg* 67(5):724–727
- Monteggia GB (1814) Lussazioni delle ossa delle estremità superiori. *Instituzioni chirurgiche* 5:131–133
- Ramirez RN, Ryan DD, Williams J, Wren TA, Ibrahim D, Weiss JM, Kay RM, Lightdale-Miric N, Skaggs DL (2014) A line drawn along the radial shaft misses the capitellum in 16% of radiographs of normal elbows. *J Pediatr Orthop* 34(8):763–767
- Ramski DE, Hennrikus WP, Bae DS, Baldwin KD, Patel NM, Waters PM, Flynn JM (2015) Pediatric Monteggia fractures: a multicenter examination of treatment strategy and early clinical and radiographic results. *J Pediatr Orthop* 35(2):115–120
- Ring D, Waters PM (1996) Operative fixation of Monteggia fractures in children. *J Bone Joint Surg* 78(5):734–739
- Silberstein MJ, Brodeur AE, Graviss ER (1979) Some vagaries of the capitellum. *J Bone Joint Surg Am* 61(2):244–247
- Souder CD, Roocroft JH, Edmonds EW (2017) Significance of the lateral humeral line for evaluating radiocapitellar alignment in children. *J Pediatr Orthop* 37(3):e150–e155
- Turner RC, Ho CA (2019) Monteggia fractures: pearls and pitfalls. *Oper Tech Orthop* 29(1):34–42

Type III Monteggia Fractures

Tyler J. Stavinocha

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Abstract

Type III Monteggia fractures are defined as proximal ulna fracture with associated lateral dislocation of the radial head (Bado (1967) Clin Orthop Relat Res 50(1):71–86; Monteggia (1814) *Instituzioni chirurgiche* 5:131–133). In children, these are the second most common Monteggia fracture type and require high clinical suspicion to prevent missed diagnosis (Bae (2016) J Pediatr Orthop. 36: S67–S70). Irregular and incomplete ossification of the skeletally immature elbow limits the accurate interpretation of static radiographs. Closed reduction maneuvers may be complicated by difficulty in maintaining reduction. Operative options include elastic stable intramedullary nailing (ESIN) or open reduction and internal fixation of the ulna with secondary reduction of the radiocapitellar joint. For

severe injuries, additional open reduction of the radio-capitellar joint may be necessary.

1 Brief Clinical History

The patient is a 7-year-old male who presented immediately following a fall from 10 ft off a playground slide, landing on his left elbow. Patient sustained an isolated injury, with focal pain and swelling to the left elbow joint. Injury radiographs are shown in Fig. 1. He demonstrated intact sensation and distal motor function throughout the left upper extremity and had palpable radial pulse.

Patient underwent conscious sedation in the emergency department with ketamine sedation monitored by an emergency medicine physician. The patient returned the following week and received repeated x-rays in plaster. There was concern for lateral subluxation of radial head with static radiographs obtained in plaster, and evaluation was supplemented with comparison films obtained of the contralateral arm, as well as examination of the immobilized elbow using mini

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Fig. 1 (a–c) Injury radiographs (a) demonstrate a proximal ulna fracture with significant apex-lateral angulation. There is incomplete cortical disruption in the concavity with plastic deformity of the medial ulnar cortex. Lateral views show minimal anterior radial head subluxation in the while AP views demonstrate complete lateral dislocation of the radiocapitellar joint. Post-reduction views (b) demonstrate reduced radiocapitellar joint on the lateral view, with improved ulnar angulation on the AP view but still some lateral displacement of the radial head. Follow-up radiographs at 1 week (c) demonstrated lateral radial head subluxation (proximal lateral radial neck is lateral to a line along the lateral edge of the ossified capitellum)



c-arm fluoroscopy in the clinic to assess several oblique views. With confirmed subluxation of the radiocapitellar joint, operative reduction and stabilization was recommended.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Left elbow type III Monteggia fracture
2. Associated ulnar medial bowing with residual plastic deformity

4 Treatment Strategy

Type III Monteggia fractures are the second most common Monteggia fracture dislocation (Bae 2016) and are defined as lateral displacement of the radiocapitellar joint in the setting of proximal ulna fractures. They may be uniquely difficult to diagnose due to the radiographic ambiguity of the skeletally immature elbow. A subluxated radial head is often noted when the radiocapitellar line (RCL), a line passing through the radial neck, does not bisect the capitellar ossification center at all degrees of elbow flexion. This parameter was initially identified by Smith (1947) in 1947, who described it based on elbow radiographs. Type I and II Monteggia fractures demonstrate this displacement, with anterior and posterior displacement, respectively. In contrast, the RCL has not been validated on the AP view and in fact

has been noted to most consistently pass through the lateral third of the capitellar ossification, which demonstrates an eccentric pattern of ossification with skeletal maturity (Souder et al. 2017; Ramirez et al. 2014; Kunkel et al. 2011; Silberstein et al. 1979).

Souder et al. (2017) attempted to validate the radiocapitellar line on the AP elbow view by reviewing the radiocapitellar line in uninjured elbow radiographs and MRIs, as compared with a series of type III Monteggia fractures. They identified the lateral humeral line (LHL), defined as a line along the lateral distal humeral condyle, parallel with the humeral shaft. On AP radiographs of normal elbows, the lateral radial neck remained medial to the lateral humeral line, whereas the neck crossed this line in established type III Monteggia fractures. Limitations to this study included a comparison sample of only three type III Monteggia fractures and the specific evaluation of anteroposterior radiographs in full elbow extension. Appreciation of radiocapitellar subluxation or dislocation may be further clouded in radiographs in elbow flexion or radiographic obliquity. As seen in this case, a dynamic evaluation using limited live fluoroscopy in clinic assisted with joint assessment but may not be available in all centers. In any case, high clinical suspicion is important, as Monteggia fractures can be missed by up to 50% of the time (Silberstein et al. 1979).

When diagnosed, treatment approach to type III Monteggia fractures follows similar principles for types I and II. Nondisplaced and greenstick fractures often show good clinical outcomes with closed reduction and casting. Stable, displaced fractures, such as transverse and short oblique fractures, may be amenable to ESIN, while long oblique and comminuted fractures may be treated with open reduction and plate fixation. Refer to the chapter entitled “Type I Monteggia Fractures” for further discussion of ulnar-based strategies for Monteggia fracture management (Bae and Waters 2005; Ramski et al. 2015; Ring and Waters 1996).

Closed reduction requires skilled manipulation and casting techniques. Reduction of the ulnar displacement, plastic deformity, and length may guide secondary reduction of the radiocapitellar joint. While type I Monteggia fractures are classically reduced with wrist supination and elbow flexion, type II and III Monteggia fractures may be better reduced and molded with the elbow in extension. A thumb spica or cuff and collar attachment may be added to prevent cast migration (Foran et al. 2017). Reduction maneuvers counteract the apex-lateral deformity of the ulna, usually with direct palpation and pressure on the radial head. Close radiographic follow-up weekly for 3 weeks is planned to identify early displacement, which may occur approximately 20% of the time (Bae 2016; Ramski et al. 2015; Ho and Turner 2019).

In this case, the radial head would reduce closed in the OR, and we used elastic stable intramedullary nail (ESIN) to maintain correction of the ulnar deformity. We used an olecranon tip starting point for straight trajectory down the ulnar intramedullary canal. The curved distal tip of the ESIN was cut to allow a larger diameter to be passed across the canal isthmus, and the proximal end was curved to be buried under the skin and limit hardware irritation prior to planned removal. It is our practice to tie a nonabsorbable braided suture to the curved proximal nail that remains under the subdermal skin layer, which facilitates identification of the nail during planned hardware removal with minimal soft tissue dissection. If the radial head is reducible, then elastic stable intramedullary nailing affords minimal exposure to maintain reduction for most non-comminuted ulnar fracture patterns.

When the radial head does not reduce closed, open reduction of the radiocapitellar joint is necessary and may be performed with a laterally based Kocher or Kaplan approach. In these approaches, it is important to pronate the forearm to draw the posterior interosseous nerve (PIN) away from its proximity to the radial neck (Lawton et al. 2007). It is further important to note that the lateral displacement of the radial head in type III Monteggia fractures and resultant soft tissue swelling may further distort this surgical anatomy. In severely displaced type III injuries that do not reduce closed, it is not uncommon to find the radial head has buttonholed through the lateral joint capsule. In these cases the capsular rent should be extended to visualize the capitellum and identify the annular ligament. In cases where the annular ligament is not torn, a nerve hook is helpful to find the central hole in the ligament and pull it back over the radial head. If it has been torn, the two ends can be tagged with suture and pulled apart to allow anatomic docking of the radial head against the capitellum, and then the ends are sutured together around the radial neck.

5 Basic Principles

1. High clinical suspicion to prevent missed diagnosis, which is reported in up to a third of cases.
2. Assessment of the radiocapitellar joint may be limited by eccentric ossification of the capitellum. On AP views of the elbow, the radiocapitellar line (RCL) most often intersects the lateral third of capitellar ossification and may miss it completely. The radial neck crossing the lateral humeral line (LHL) may be evidence the radiocapitellar joint is subluxated or dislocated.
3. Early postoperative radiographic monitoring weekly for at least 3 weeks following successful closed reduction is recommended.

4. Consider internal fixation for length-unstable ulnar fracture patterns or those with substantial bowing that cannot be reduced with closed techniques.
5. Establish ulnar length and alignment primarily to prevent unnecessary radiocapitellar joint malalignment.
6. Severe cases may require open reduction of the radiocapitellar joint, approached through a modified Kocher or Kaplan exposure. Forearm pronation throughout this approach is recommended to pull the PIN away from surgical field as it pass around the radial neck.
7. Surgical intervention primarily aims to restore radiocapitellar joint stability with bone healing to promote joint motion. To allow for healing of disrupted ligaments and joint capsule of the radiocapitellar joint, the elbow is typically immobilized for 4 weeks after surgical fixation.

6 Images During Treatment

See Fig. 2.

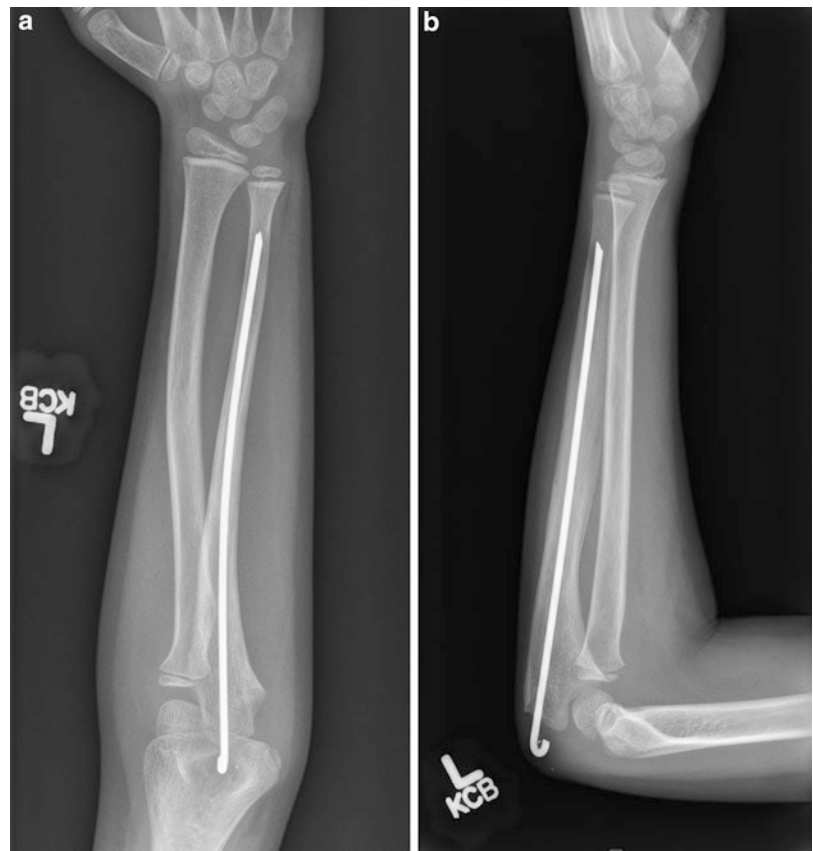
7 Technical Pearls

1. In this case, two things facilitated the passage of a larger diameter wire through the ulnar intramedullary space. First, a starting point was established through the olecranon tip, allowing a more direct trajectory to the ulnar intramedullary canal. Second, the flexible rod was cut to remove the curved tip, allowing a larger pin diameter to pass through the canal.
2. The proximal end of the flexible nail was hooked to limit sharp hardware irritation.

Fig. 2 (a–d) Intraoperative fluoroscopy images show passage of the ulnar flexible intramedullary rod. The apex-lateral ulnar plastic deformity is corrected and radiocapitellar joint is reduced. The proximal end of the rod is hooked to limit hardware irritation



Fig. 3 (a, b) AP and lateral views of the forearm at 3 months postoperatively. Full ulnar healing is evident with maintained reduction of the radiocapitellar joint



3. A single braided nonabsorbable suture was tied to the hooked tip with strands left subdermally to facilitate implant tip localization with planned hardware removal at a later time, typically 4–6 months after injury when complete radiographic healing of the ulna is noted.
4. The intramedullary rod may be contoured or bowed to counteract plastic deforming forces of the ulna.
4. When the radiocapitellar joint is approached through a Kocher or Kaplan surgical interval, forearm pronation is recommended to help protect the PIN as it passes across the radial neck.

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

1. High clinical suspicion to prevent missed diagnosis, which is reported in up to a third of cases.
2. Early postoperative radiographic monitoring for at least 3 weeks following successful closed reduction.
3. When performing ESIN, we recommend using a larger wire to provide stout counteraction to ulnar deformity and maintain stable reduction.

References and Suggested Readings

- Bado JL (1967) The Monteggia lesion. *Clin Orthop Relat Res* 50:71–86
- Bae DS (2016) Successful strategies for managing Monteggia injuries. *J Pediatr Orthop* 36:S67–S70
- Bae DS, Waters PM (2005) Surgical treatment of acute and chronic Monteggia fracture-dislocations. *Oper Tech Orthop* 15(4):308–314
- Foran I, Upasani VV, Wallace CD, Britt E, Bastrom TP, Bomar JD, Pennock AT (2017) Acute pediatric Monteggia fractures: a conservative approach to stabilization. *J Pediatr Orthop* 37(6):e335–e341
- Gleeson AP, Beattie TF (1994) Monteggia fracture-dislocation in children. *Emerg Med J* 11(3):192–194
- Ho CA, Turner RC (2019) Monteggia fractures: pearls and pitfalls. *Oper Tech Orthop*
- Kunkel S, Cornwall R, Little K, Jain V, Mehlman C, Tamai J (2011) Limitations of the radiocapitellar line for assessment of pediatric elbow radiographs. *J Pediatr Orthop* 31(6):628–632
- Lawton JN, Cameron-Donaldson M, Blazar PE, Moore JR (2007) Anatomic considerations regarding the posterior interosseous nerve at the elbow. *J Shoulder Elb Surg* 16(4):502–507

- Monteggia GB (1814) Lussazioni delle ossa delle estremità superiori. *Istituzioni chirurgiche* 5:131–133
- Ramirez RN, Ryan DD, Williams J, Wren TA, Ibrahim D, Weiss JM, Kay RM, Lightdale-Miric N, Skaggs DL (2014) A line drawn along the radial shaft misses the capitellum in 16% of radiographs of normal elbows. *J Pediatr Orthop* 34(8):763–767
- Ramski DE, Hennrikus WP, Bae DS, Baldwin KD, Patel NM, Waters PM, Flynn JM (2015) Pediatric Monteggia fractures: a multicenter examination of treatment strategy and early clinical and radiographic results. *J Pediatr Orthop* 35(2):115–120
- Ring D, Waters PM (1996) Operative fixation of Monteggia fractures in children. *J Bone Joint Surg* 78(5):734–739
- Silberstein MJ, Brodeur AE, Graviss ER (1979) Some vagaries of the capitellum. *J Bone Joint Surg Am* 61(2):244–247
- Smith FM (1947) Monteggia fractures; an analysis of 25 consecutive fresh injuries. *Surg Gynecol Obstet* 85(5):630–640
- Souder CD, Roocroft JH, Edmonds EW (2017) Significance of the lateral humeral line for evaluating radiocapitellar alignment in children. *J Pediatr Orthop* 37(3):e150–e155

Radial Neck Fractures: Introduction and Classification

Theddy Slongo

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Abstract

In childhood the majority of fractures around the proximal radius are radial neck fractures, according the AO Pediatric classification (Slongo et al. J Pediatr Orthop 26:43–49, 2006, AO Pediatric comprehensive classification of long bone fractures (PCCF). AO Publishing, Davos, 2007) 21r-M and 21r-E fractures. Real radial head fractures are rare and are not addressed in this case description. The **absolute gold standard** for the treatment of these fractures is closed indirect reduction and internal fixation according the ESIN (elastic–stable–intramedullary–nailing) technique (Dietz et al. 2006). Open reduction and internal fixation should be avoided because of the associated problems of AVN, unstable fixation, joint

stiffness, and radio-ulnar synostosis with bad functional outcomes.

On the other hand, the **ESIN method** because of it superior results and ease of use leads to a more frequent indications for operative treatment.

In the table below, there is an overview of the actual indication-philosophy and treatment modalities according the fracture type.

1 Injury Mechanism

To reproduce the injury mechanism of this fracture is difficult; in many textbooks we have nice illustrations of the theoretical mechanisms. We know that in principle the radial head is

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protected by the stable situation between the humerus and ulna. Therefore, two main mechanisms are possible for the majority of the cases, we call them “flexion type” fractures where the radial head is in flexion in relation to the radial shaft.

1. High valgus stress on the extended elbow; this leads to a compression or fracture of the metaphyseal segment with more or less angulation/dislocation of the radial head.
2. Axial elbow dislocation with or without valgus stress.

2 Preoperative Clinical Photos and Radiographs

The biggest problem of this fracture is to obtain good images, clear AP and lateral. Most of the injury films we see are oblique (Fig. 1a, b) and can lead to incorrect diagnosis or classification. Therefore, it is important to discuss with the radiologist to obtain high quality x-rays (Fig. 2a, b). One of the options is using the image intensifier (Fig. 3).

Fig. 1 (a, b) An oblique, suboptimal x-ray

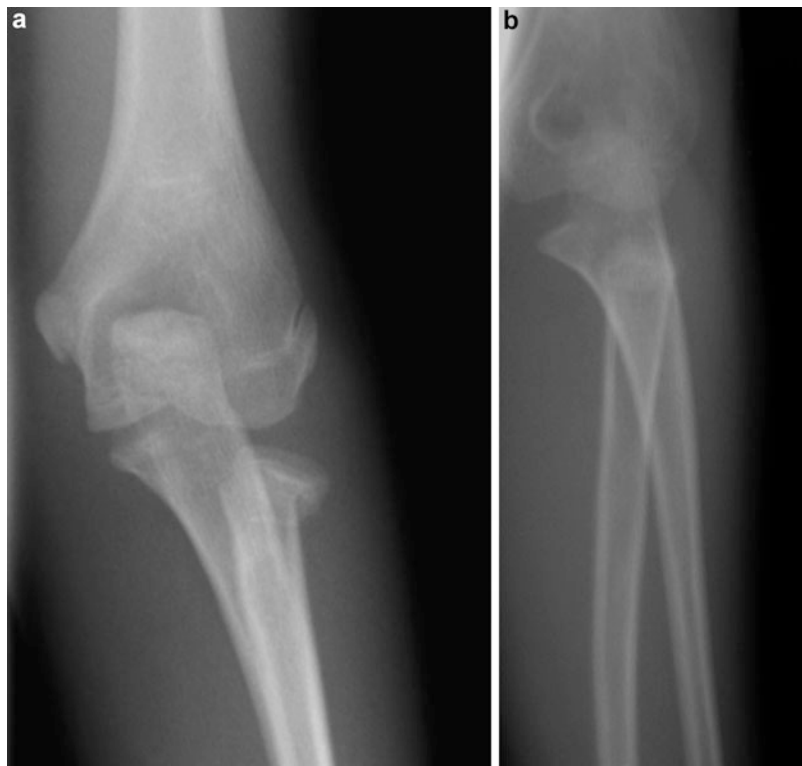


Fig. 2 (a, b) A correct AP and lateral x-ray



3 **Classification for Treatment of Radial Neck Fractures and Problem Lists**

3.1 **Indication for Only Immobilization and No Active Operative Intervention According the Classification and Problem List**

See Tables 1 and 2

Problem List:

- 1. Exact analysis of the fracture pattern and morphology as a pre-requisite for decision making

Fig. 3 An optimal projection under image intensifier



- 2. Do I have the material/bandages for conservative treatment?
- 3. Are the parents and the child complaining?
- 4. Are the follow-ups scheduled?

3.2 **Indication for Closed Reduction and Internal Operative Stabilization (CRIF) and Preoperative Problem List**

See Tables 3 and 4

Preoperative Problem List:

- 1. Exact analysis of the fracture pattern and morphology as a prerequisite for decision making
- 2. Which method of stabilization is chosen?
- 3. If I plan to perform ESIN; do I have the skills for this technique?
- 4. Postoperative protocol available?
- 5. Comprehensive information for the parents/patient

4 **Treatment Strategy**

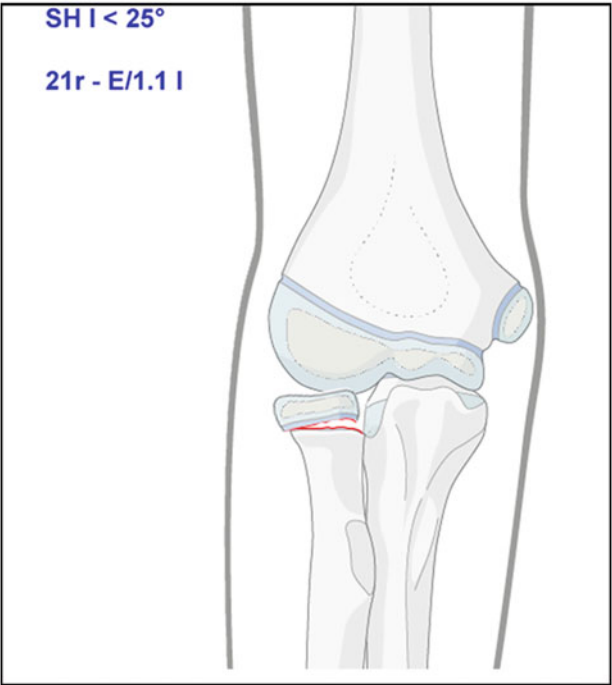
According the fracture types, shown in the table above, we have a clear process for the “decision making” for the correct treatment. In our hands, over the last 20 years worldwide this method has been accepted and propagated by all Paediatric Trauma groups for all fractures shown in Table 3 and 4, the ESIN technique as the preferable treatment.

All fractures shown in Tables 1 and 2 do not need manipulation; only immobilization is required.

Table 1 Graphic drawings according the AO Paediatric Classification for nonoperative treatment: metaphyseal fractures

<div>21r - M/2.1</div> <div>Buckle Fracture</div>	<div>21r - M/2.1</div> <div>complete fracture</div>	<div>21r - M/3.1 I</div> <div>complete fracture</div>
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Table 2 Graphic drawing according the AO Paediatric Classification for nonoperative treatment: epiphyseal fractures fracture



5 Basic Principles

Nonoperative Treatment:
Knowledge and skills for correct plaster cast application;
traditional plaster of Paris or fiber glass cast

Operative Treatment:
Knowledge and skills for closed reduction using the ESIN technique
In case of extension type radial neck fractures skills for atraumatic mini-open reduction in combination with ESIN technique

6 Images During Treatment

For closed treatment by ESIN technique, an image intensifier should be used (Fig. 4).

Table 3 Graphic drawings according the AO Paediatric Classification for operative treatment: metaphyseal fractures


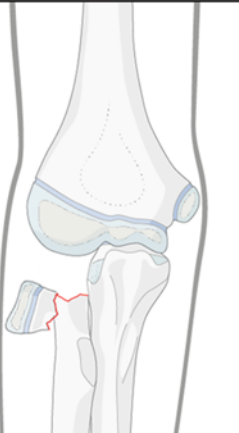
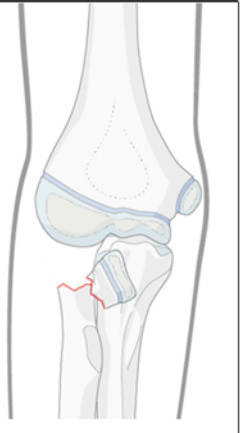
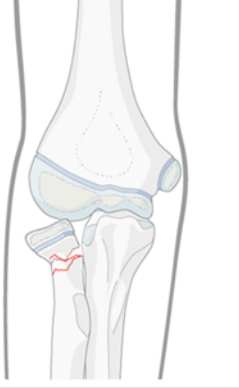
<p>21r - M/3.1 II</p> <p>complete fracture more 25°</p> 	<p>21r - M/3.1 III</p> <p>complete fracture more 25° fully displaced</p> 	<p>21r - M/3.1 III</p> <p>complete fracture more 25° fully displaced to medial</p> 
<p>21r - M/3.2 II</p> <p>complete fracture multifragmentary more 25°</p> 		

Table 4 Graphic drawings according the AO Paediatric Classification for operative treatment: physeal fractures



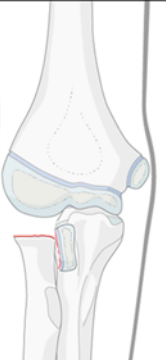



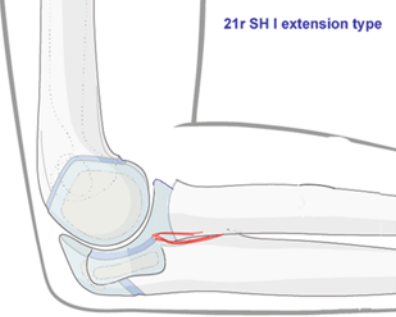
<div>SH I > 25°</div> <div>21r - E/1.1 II</div> 	<div>SH I > 25°</div> <div>21r - E/1.1 III</div> 	<div>SH I > 25°</div> <div>21r - E/1.1 III</div> <div>medial dislocation</div> 
<div>SH II < 25°</div> <div>21- E/2.1 II</div> 	<div>SH II > 30°</div> <div>fully displaced</div> 	<div>SH II < 25°</div> <div>21- E/2.1 III</div> <div>medial dislocation</div> 
 <div>21r SH I extension type</div>		

Fig. 4 An image intensifier with Laser (red lines on the skin) facilitates the optimal positioning of the fractured segment and reduces irradiation (dosage and time)



Fig. 5 Four weeks after closed reduction and intramedullary fixation the child has full pronation and supination

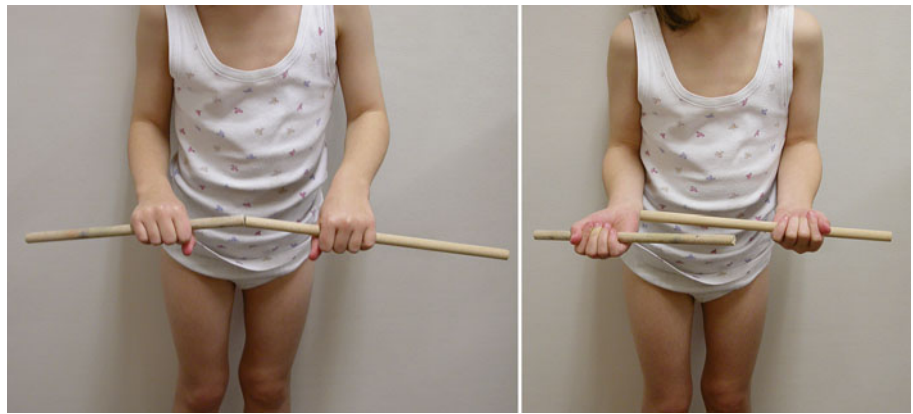


Fig. 6 (a) shows the injury film of a displaced radial neck fracture which in our hands is an indication for reduction and stabilization; (b) shows the perfect result after reduction and stabilization

7 Technical Pearls

The closed, indirect reduction using the ESIN method has the highest opportunity for an optimal result because of stable fixation, early functional movement, and cast free postoperative management.

8 Outcome Clinical Photos and Radiographs

See Figs. 5 and 6

9 Cross-References

- [Radial Neck Fracture: Operative Treatment \(ESIN\) “Joy-Stick” Technique](#)
- [Radial Neck Fractures: Conservative Treatment](#)

References and Suggested Readings

- Basmajian HG, Choi PD, Huh K, Sankar WN, Wells L, Arkader A (2014) A radial neck fractures in children: experience from two level-1 trauma centers. *J Pediatr Orthop B* 23(4):369–374
- Dietz HG, Schmittenbecher PP, Slongo TF, Wilkins KE (2006) Elastic stable intramedullary nailing (ESIN) in children, AO manual of fracture management. Thieme, Stuttgart
- Falciglia F, Giordano M, Aulisa AG, Di Lazzaro A, Guzzanti V (2014) Radial neck fractures in children: results when open reduction is indicated. *J Pediatr Orthop* 34(8):756–762
- Gonzalez-Herranz P, Alvarez-Romera A, Burgos J, Rapariz JM, Hevia E (1997) Displaced radial neck fractures in children treated by closed intramedullary pinning (Metaizeau technique). *J Pediatr Orthop* 17:325–331
- Klitscher D, Richter S, Bodenschatz K et al (2009) Evaluation of severely displaced radial neck fractures in children treated with elastic stable intramedullary nailing. *J Pediatr Orthop* 29:698–703
- Lascombe P (2006) Embrochage centromédullaire élastique stable. Elsevier, Masson, Issy-les Moulineaux
- Metaizeau JP, Lascombes P, Lemelle JL, Finlayson D, Prevot J (1993) Reduction and fixation of displaced radial neck fractures by closed intramedullary pinning. *J Pediatr Orthop* 13:355–360
- Schmittenbecher PP, Haevernick B, Herold A, Knorr P, Schmid E (2005a) Treatment decision, method of osteosynthesis, and outcome in radial neck fractures in children. *J Pediatr Orthop* 25:45–50
- Schmittenbecher PP, Haevernick B, Herold A, Knorr P, Schmid E (2005b) Treatment decision, method of osteosynthesis, and outcome in radial neck fractures in children: a multicenter study. *J Pediatr Orthop* 25:45–50
- Slongo T, Audigé L, Schlickewei W, Clavert JM, Hunter J (2006) Development and validation of the AO pediatric comprehensive classification of long bone fractures by the pediatric expert group of the AO foundation in collaboration with AO clinical investigation and documentation and the international association for pediatric traumatology. *J Pediatr Orthop* 26:43–49
- Slongo T, Audigé L, AO Classification Group (2007) AO Pediatric comprehensive classification of long bone fractures (PCCF). AO Publishing, Davos
- Vocke AK, von Laer L (1998) Displaced fractures of the radial neck in children: Long-term results and prognosis of conservative treatment. *J Pediatr Orthop Part B* 1(7):217–222

Radial Neck Fractures: Conservative Treatment

Theddy Slongo

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Abstract

In childhood, the majority of fractures around the proximal radius are radial neck fractures, according the AO Pediatric classification (Slongo et al. J Pediatr Orthop 26:43–49, 2006, AO Pediatric comprehensive classification of long bone fractures (PCCF). AO Publishing, Davos, 2007) 21r-M and 21r-E fractures. With the introduction of the ESIN method, the indication for closed reduction and stabilization has been significantly expanded. So today we recommend treating only slightly dislocated and absolutely stable fractures conservatively. At the same time conservatively means that we do not make an active reduction. The acceptable malalignment depends on the age of the child and the remaining remodeling capacity. Tables 1 and 2 are showing the possible fracture pattern we recommend for nonoperative treatment.

1 Brief Clinical History

An 8-year-old girl has fallen on his extended arm of a climbing frame. She had immediately severe pain and over the next minutes a swollen elbow was seen. The child was taken to the emergency department by the parents 3 h after the injury.

In the emergency, we have seen an 8-year-old child in good condition, the arm was fixed to the thorax.

2 Preoperative Clinical Photos and Radiographs

At the first examination, we have seen a strongly swollen elbow (Fig. 1). The fingers could be moved well despite the pain. Sensibility and circulation was normal.

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Table 1 Graphic drawings according the AO Paediatric Classification for nonoperative treatment of metaphyseal fractures

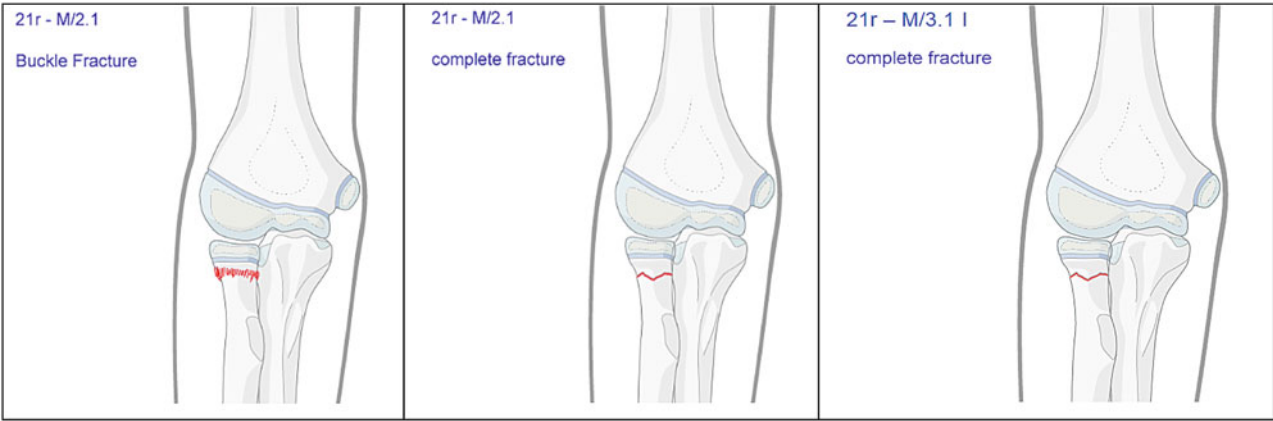


Table 2 Graphic drawing according the AO Paediatric Classification for nonoperative treatment of epiphyseal fractures fracture



Due to the clinical examination and the case history, an ap and lateral x-ray of the elbow was performed.

Figure 2 shows the ap and lateral x-rays of the elbow with a minimal angulated and displaced radial neck fracture (21 – M/3.1 I).

3 Preoperative Problem List

As we had no other injuries and the neuro-vascular situation is normal, according our algorithm, this radial neck fractures type I is treated conservatively. Our plan is to perform only immobilization of the elbow for 4 weeks in a long arm cast.



Fig. 1 Clinical picture of the severely swollen elbow of this 8-year-old child. The explanation why we have a swelling over the olecranon is clearly seen in Fig. 11

4 Treatment Strategy

To transfer the child in the fracture clinic for cast application. In a younger child, even the procedure makes no pain and it is recommended to give some pain medicaments or tranquilizer:

5 Basic Principles

It is important to show and explain every step of your planned treatment as the child is not under anesthesia. The presence of the parent (at least mother or father) should be always possible and should be a matter of course today.

Fig. 2 (a) Ap and (b) lateral x-ray shows a minimal angulated radial neck fracture less than 30° ; (b) in the lateral view, we see only a minimal compressed zone without displacement

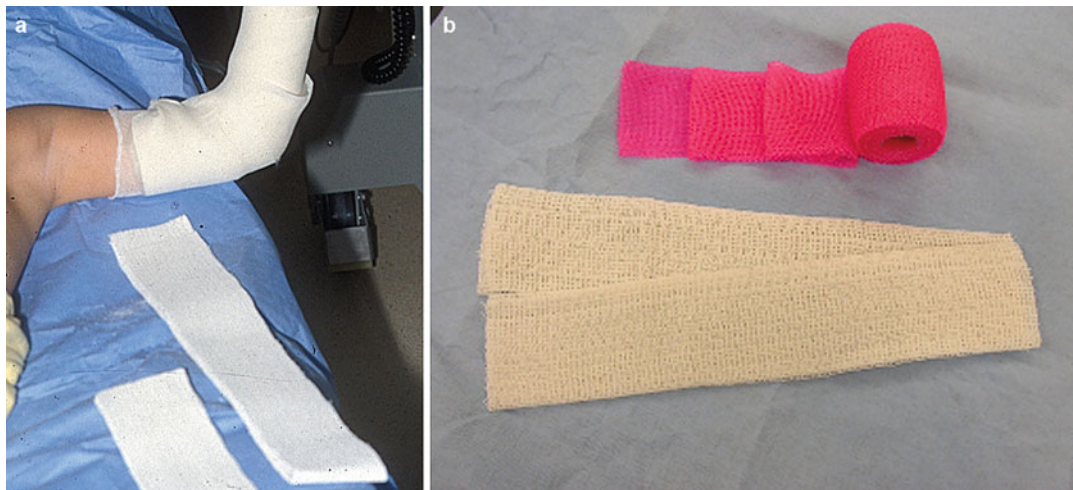


Fig. 3 A short (volar) and a long (dorsal) plaster cast splint with a least 6 layers are prepared for long arm fixation. In this picture, the arm is already padded (a). In (b) we see the similar prepared fiber cast

Depending on the fixation you are using plaster cast or fiber cast; it is important to have all material well prepared. (Fig. 3a, b).

Depending on the clinic guidelines, the arm should be fixed in a circular cast or in a long arm dorso-volar plaster splint. Since the arm can occasionally swell up very strongly, we prefer the fixation with dorso-volar plaster splints (Fig. 4a, b).

6 Images During Treatment

The easiest way to apply a neutral long arm plaster splint (if no manipulation is required) is to hang up the arm on finger straps (Fig. 5). This allows a stress-free working even you have no help and a 360° access to the

Fig. 4 (a) Demonstrates a fixation with circular fiber cast. (b) shows the application of the two (volar and dorsal) plaster cast splints. We recommend to start with the volar one which can be easily held with two fingers



Fig. 5 The forearm is fixed with 3 or 4 finger straps in a high that the elbow has a right angle



Fig. 6 The arm is protected by a sticking and then the arm is padded



Fig. 7 Application of the plaster cast splints with are then fixed by a paper bandage



Fig. 8 For a correct lateral x-ray examination, it is recommended to rotate the C-arm 45–50° as shown in this picture

arm. In addition, working in a hanging position of the arm prevents any punctual pressure on the cast, which can cause skin lesions.

Figures 5, 6, 7, 8, and 9 show the different steps of the long arm plaster application (plaster-splint technique).



Fig. 9 At the end, the two plaster cast splints are definitively fixed with an elastic bandage

7 Technical Pearls

In younger children, it is recommended to apply a stable long arm cast so that the child is not able to remove it. In older children, age over 12–13, a splint is normally sufficient so that the child can remove it for shower and some gentle exercises (gentle flexion and extension as well as pro- and supination) to prevent stiffness. We have to know or recognize that the plaster cast or split does not hold the fracture itself and the cast is only for protection and immobilization.

8 Outcome Clinical Photos and Radiographs

An immobilization of 3–4 weeks is sufficient, depending on the age of the child. In this case, the plaster splint was removed the first time after 2 weeks because of some pain at the olecranon region. The x-ray shows an additional fracture at the olecranon which was not recognized initially (Fig. 10). A new cast was applied again for 2 weeks. Figure 11 shows the situation after 4 ½ weeks with a good consolidation of both fractures.

9 Avoiding and Managing Problems

Depending on the child's activity and arm mobilization, the unrestricted use of the forearm was allowed.



Fig. 10 This x-ray was made after 2 weeks without plaster cast because of unclear pain in the olecranon. We see now an un-displaced olecranon fracture, which was not recognized initially



Fig. 11 Consolidation of both fractures is documented after 4 ½ weeks

In our hand, for such an unproblematic fracture, no follow-up is planned. The parents are requested for a visit if in one month the arm cannot be used normally.

References and Suggested Reading

Basmajian HG, Choi PD, Huh K, Sankar WN, Wells L, Arkader A (2014) A radial neck fractures in children: experience from two level-1 trauma centers. *J Pediatr Orthop B* 23(4):369–374

- Falciglia F, Giordano M, Aulisa AG, Di Lazzaro A, Guzzanti V (2014) Radial neck fractures in children: results when open reduction is indicated. *J Pediatr Orthop* 34(8):756–762
- Gonzalez-Herranz P, Alvarez-Romera A, Burgos J, Rapariz JM, Hevia E (1997) Displaced radial neck fractures in children treated by closed intramedullary pinning (Metaizeau technique). *J Pediatr Orthop* 17:325–331
- Klitscher D, Richter S, Bodenschatz K et al (2009) Evaluation of severely displaced radial neck fractures in children treated with elastic stable intramedullary nailing. *J Pediatr Orthop* 29:698–703
- Lascombe P (2006) *Embrochage centromédullaire élastique stable*. Elsevier, Masson, Issy-les Moulineaux
- Metaizeau JP, Lascombes P, Lemelle JL, Finlayson D, Prevot J (1993) Reduction and fixation of displaced radial neck fractures by closed intramedullary pinning. *J Pediatr Orthop* 13:355–360
- Schmittenebecher PP, Haevernick B, Herold A, Knorr P, Schmid E (2005) Treatment decision, method of osteosynthesis, and outcome in radial neck fractures in children: a multicenter study. *J Pediatr Orthop* 25:45–50
- Slongo T, Audigé L, Schlickewei W, Clavert JM, Hunter J (2006) Development and validation of the AO pediatric comprehensive classification of long bone fractures by the pediatric expert group of the AO foundation in collaboration with AO clinical investigation and documentation and the international association for pediatric traumatology. *J Pediatr Orthop* 26:43–49
- Slongo T, Audigé L, AO Classification Group (2007) *AO Pediatric comprehensive classification of long bone fractures (PCCF)*. AO Publishing, Davos
- Vocke AK, von Laer L (1998) Displaced fractures of the radial neck in children: long-term results and prognosis of conservative treatment. *J Pediatr Orthop Part B* 1(7):217–222

Radial Neck Fracture: Conservative Treatment, Pitfalls, and Problems

Theddy Slongo

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Abstract

In childhood, the majority of fractures around the proximal radius are radial neck fractures, according to the AO Pediatric Comprehensive Classification (Slongo et al. 2006, 2007) 21r- M and 21r – E fractures. With the introduction of the Elastic Stable Intramedullary Nailing, (ESIN) method, the indication for closed reduction and stabilization has been significantly expanded. So today it is recommended to treat only slightly dislocated and absolutely stable fractures conservatively. At the same time, “conservatively” means avoiding an active reduction. The acceptable malalignment depends on the age of the child and the remaining remodeling capacity.

1 Brief Clinical History

An 11-year-old boy injured his elbow at a fall with the bicycle. The child was sent for a second opinion after some months because of the limited elbow motion. Medical history described the following situation:

Emergency department described an 11-year-old boy in good condition; the arm was fixed with a temporary splint.

The elbow was a little swollen; the skin over the olecranon was scratched.

Due to the clinical examination and the case history, an AP and lateral x-ray of the elbow was performed.

2 Preoperative Clinical Photos and Radiographs

See (Fig. 1).

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3 **Preoperative Problem List**

As there were no other injuries and the neurovascular situation was normal, according to the recommendations in the literature, this radial neck fracture type I was treated conservatively. Tables 1 and 2 show the possible fracture pattern recommended for non-operative treatment.

4 **Treatment Strategy**

The plan was to perform immobilization of the elbow for 4 weeks in a long arm fiberglass cast.

5 **Basic Principles**

5.1 **Images During Treatment**




The first radiologic follow-up was scheduled 3 days post-injury with the explanation that it could be assessed for fracture stability.

The treating surgeon should consider the stability of this fracture. A small comminution zone in the metaphysis can be seen, a clear sign of potential instability. It is recommended to perform cast-free x-rays in this special situation because the plaster or fiberglass cast does not fix the fracture; it only provides an immobilization (Figs. 2 and 3).

Fig. 1 Injury film (AP and lateral x-rays) of the elbow of an 11-year-old boy following a bicycle injury. It shows a minimally angulated and displaced radial neck fracture (21 – M/3.1 I)



Table 1 Graphic drawings according to the AO Pediatric Classification for non-operative treatment of metaphyseal fractures

<p>21r - M/2.1</p> <p>Buckle Fracture</p> 	<p>21r - M/2.1</p> <p>complete fracture</p> 	<p>21r – M/3.1 I</p> <p>complete fracture</p> 
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6 Technical Pearls

6.1 Outcome Clinical Photos and Radiographs

The next x-ray was taken 5 months after injury. At this time, the child had a recent limitation of pronation and supination. The flexion was 15° less to the non-injured side. During sports, the child had some pain in the elbow. Figure 4

Table 2 Graphic drawing according to the AO Pediatric Comprehensive Classification for non-operative treatment of epiphyseal fractures

SH I < 25°

21r - E/1.1 I



shows the subluxation of the radial head, and in addition, a bony fragment, a sign of fracture of the border of the radial neck, can be seen as a consequence of impingement force during sport activity.

At least at this moment, an ulna flexion osteotomy (like in missed Monteggia lesions) should be considered before the wrong joint situation is fixed and the radial condyle form gets flat.

The last x-ray was at 7 months after the child's first visit to the clinic (Fig. 5). The operation as mentioned above was suggested, but the parents and the child refused treatment even as the child had severe problems.

6.2 Avoiding and Managing Problems

This case clearly shows that even a stable fracture can displace or angulate in a plaster cast. In this specific situation, a plaster cast immobilizes the elbow but does not fix the fracture.

The initial treatment of immobilization was correct. The problem was not to recognize that the fracture is unstable and not to manage the subsequent displacement.

What was the initial trauma? Are there signs of an overlooked Monteggia lesion. Is there a plastic deformity of the ulna?

A retrospective analysis of the initial injury film showed no signs of a Monteggia lesion. The comminution seen in the first follow-up was a clear sign that there was a severe trauma. What we have to learn from this case? At least at the 3 -day follow up x-ray would should recognize the unstable situation. At this time it is not too late to convert to a stable fixation; e.g. with ESIN method.

Fig. 2 The first follow-up x-ray at day 3 was of good quality, thanks to the fiberglass cast used. It shows similar position of the radial head, but in addition we see some comminution, especially in the AP film. There were dislocation and impaction of the radial head, pointing to a crushed zone causing instability of the fracture



Fig. 3 The cast was removed at week 4. The x-ray shows a recent callus formation, implying that the trauma was more severe than initially recognized. In addition, we see a minimal dicentric radial head in both planes. At least at this moment, a reevaluation should be considered for a revision and stable fixation

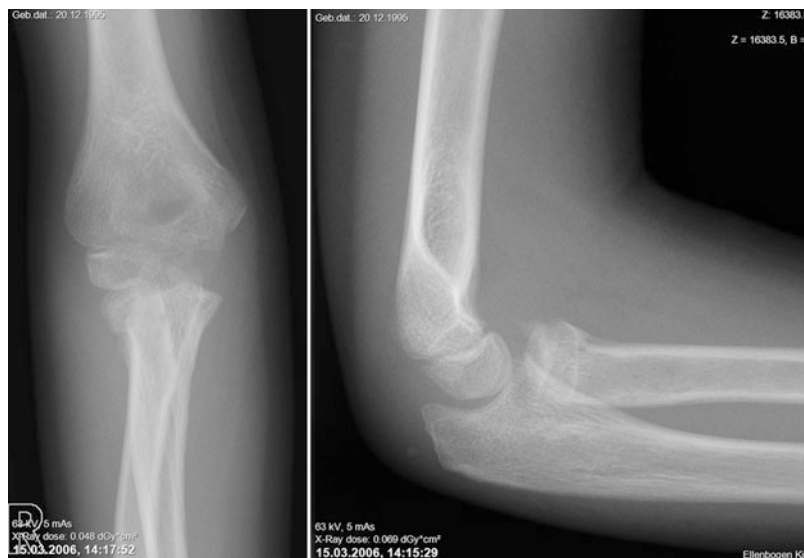


Fig. 4 A next control was made after 5 months post-injury. Now the radial head is subluxated; the lateral view shows an unconsolidated bony fragment. The sclerotic zone of the proximal radio-ulnar joint is still apparent. At this moment, it would be possible to correct the subluxation by angular ulna osteotomy



Fig. 5 The last x-ray shows the established subluxation of the radial head. The fragment is still visible. On the other hand, the concavity of the proximal radio-ulnar joint disappears; this is a problematic sign for reduction



References and Suggested Readings

- Basmajian HG, Choi PD, Huh K, Sankar WN, Wells L, Arkader A (2014) Radial neck fractures in children: experience from two level-1 trauma centers. *J Pediatr Orthop B* 23(4):369–374
- Falciglia F, Giordano M, Aulisa AG, Di Lazzaro A, Guzzanti V (2014) Radial neck fractures in children: results when open reduction is indicated. *J Pediatr Orthop* 34(8):756–762
- Gonzalez-Herranz P, Alvarez-Romera A, Burgos J, Rapariz JM, Hevia E (1997) Displaced radial neck fractures in children treated by closed intramedullary pinning (Metaizeau technique). *J Pediatr Orthop* 17:325–331
- Klitscher D, Richter S, Bodenschatz K et al (2009) Evaluation of severely displaced radial neck fractures in children treated with elastic stable intramedullary nailing. *J Pediatr Orthop* 29:698–703
- Lascombe P (2006) *Embrochage centromédullaire élastique stable*. Elsevier, Masson, Issy-les Moulineaux
- Metaizeau JP, Lascombes P, Lemelle JL, Finlayson D, Prevot J (1993) Reduction and fixation of displaced radial neck fractures by closed intramedullary pinning. *J Pediatr Orthop* 13:355–360
- Schmittenebecher PP, Haevernick B, Herold A, Knorr P, Schmid E (2005) Treatment decision, method of osteosynthesis, and outcome in radial neck fractures in children: a multicenter study. *J Pediatr Orthop* 25:45–50
- Slongo T, Audigé L, Schlickewei W, Clavert JM, Hunter J (2006) Development and validation of the AO pediatric comprehensive classification of long bone fractures by the pediatric expert group of the AO foundation in collaboration with AO clinical investigation and documentation and the international association for pediatric traumatology. *J Pediatr Orthop* 26:43–49
- Slongo T, Audigé L, AO Classification Group (2007) *AO Pediatric comprehensive classification of long bone fractures (PCCF)*. AO Publishing, Davos
- Vocke AK, von Laer L (1998) Displaced fractures of the radial neck in children: Long-term results and prognosis of conservative treatment. *J Pediatr Orthop Part B* 7:217–222

Radial Neck Fractures: Operative Treatment (ESIN)

Theddy Slongo

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Abstract

In childhood, the majority of fractures around the proximal radius are radial neck fractures, according to the AO Pediatric Classification (Slongo et al. 2006, 2007) 21r – M and 21r – E fractures. With the introduction of the ESIN method, the indication for closed reduction and stabilization has been significantly expanded. So today we recommend treating only slightly displaced or absolutely stable fractures conservatively. Conservative treatment means that we do not perform an active reduction. The acceptable displacement depends on the age of the child and the remaining remodeling capacity.

1 Brief Clinical History

An 11-year-old girl fell from a horse. She suffered a minor head injury and an injury at the right elbow. She immediately had severe pain in her right forearm. The child was taken to the emergency department by the ambulance within 30 min after the injury.

In the emergency room, the 11-year-old girl presented herself as well oriented, the arm in a sling. The fingers could be moved well despite the pain. Sensation and circulation were normal.

2 Preoperative Clinical Photos and Radiographs

Due to the clinical examination and the case history, an AP and lateral X-ray of the elbow and the forearm was performed (Fig. 1).

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3 Preoperative Problem List

There were no other skeletal injuries, the neurovascular status was normal, the associated head injury is minor, and the girl was stable. An operation for the fracture was planned, according to the algorithm of Type II and II fractures. This was not an emergency situation.

This fracture is never an emergency surgery, and the child profits from optimizing resources with experienced surgeon and team during regular hours of operation.

4 Treatment Strategy

Indication for active operative intervention takes place according the AO Pediatric Classification for operative treatment.

Tables 1 and 2 show the possible fracture pattern for which operative treatment is recommended.

The degree of displacement of this fracture is a perfect indication to use the closed, indirect reduction and intramedullary stabilization ESIN (elastic stable

Fig. 1 Shows the AP and lateral X-rays of the elbow with a more than 45° angulated radial head which is additionally translated more than 50% of the shaft diameter (21 – E/3.1 II) diagnosed as a Salter-Harris II fracture



Table 1 Graphic drawings according the AO Pediatric Classification for operative treatment of metaphyseal fractures

21 – M/3.1 II	21 – M/3.1 III	21 – M/3.2 II	21 – M/3.2 III

Table 2 Graphic drawing according the AO Pediatric Classification for operative treatment of epiphyseal fractures

21 – E/3.1 II	21 – E/3.1 III	21 – E/3.2 II	21 – E/3.2 III



Fig. 2 Recommended positioning of the sterile-draped forearm on the image intensifier



Fig. 3 Orientation/rotation of the proximal forearm for a correct visualization of the displacement/angulation of the radial neck fracture

intramedullary nailing) technique. It's important that a skilled surgeon is performing this ESIN technique.

On the other hand, as this fracture can be scheduled during regular operating hours, it allows for “teaching” this procedure, assisted by an ESIN-experienced surgeon.

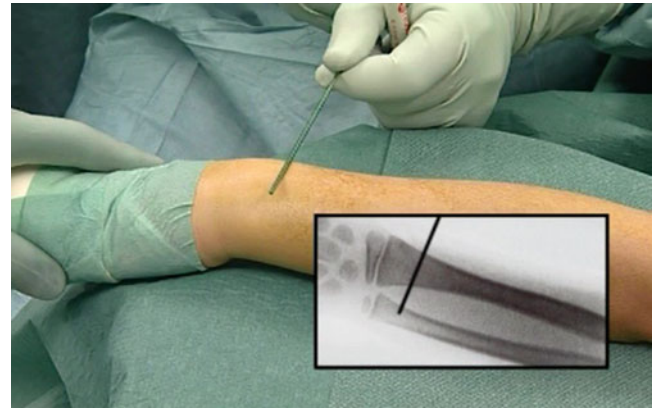


Fig. 4 Determination of the level of the entry point over the Lister's tubercle under intensifier control

5 Basic Principles

1. Insertion of an elastic nail (2.0 mm or 2.5 mm) from the distal metaphysis of the radius, depending on the age/size of the child.
2. Advancement of the nail to the fracture line.
3. Orientation of the nail tip toward the biggest angulation of the radial head and insertion of the nail tip in the head.
4. A combination of external pressure to the radial head and internal reduction of the radial head by rotating the nail.
5. Fixation of the reduced radial head.
6. Free functional movement should be achieved.
7. Plaster-free mobilization of the forearm postoperative.

6 Images During Treatment

Positioning of the sterile-draped forearm on the image intensifier (Figs. 2 and 3).

Identification of the distal entry point. Today it is recommended to use the Lister's tubercle approach or the traditional dorso-radial approach. Figure 4 shows the level of the skin incision, along the skin line transversely. This level should be checked under the intensifier.

The skin incision is then performed followed by a blunt dissection up to Lister's tubercle, protecting the retinaculum, as well as to the tendons (Figs. 5 and 6).

Figure 7 shows the position of the awl, directly on the bone. A blind approach should be avoided. This entry point and the correct position of the awl must be checked under the intensifier.

At a next step, the proximal third of the nail should be precontoured as shown in the pictures. This facilitates the nail insertion and the indirect head reduction once the nail has reached the radial head (Fig. 8).

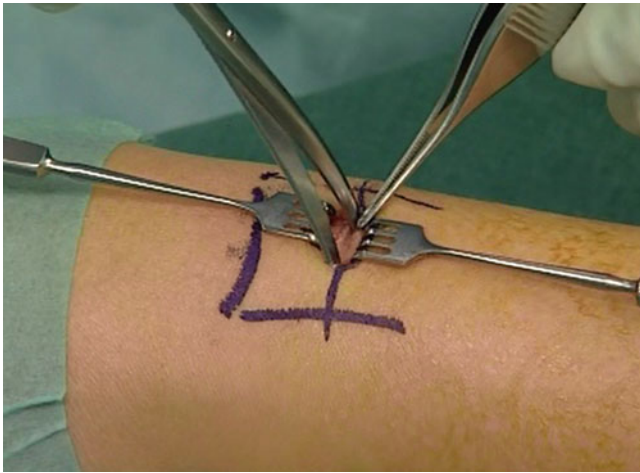


Fig. 5 3 cm long transverse skin incision along the skin lines



Fig. 8 Prebending of the first 5 cm of the nail for a better advancement and reduction of the radial neck/head

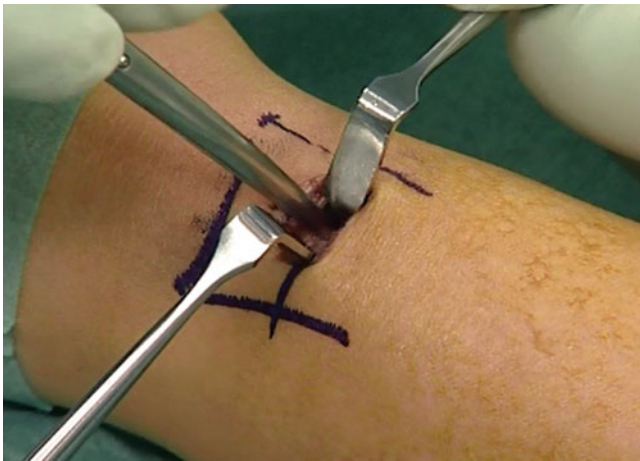


Fig. 6 Blunt dissection of the subcutaneous layers and the tendons



Fig. 9 Insertion of the nail under visual control; the alignment of the nail curve must be checked under image intensifier control

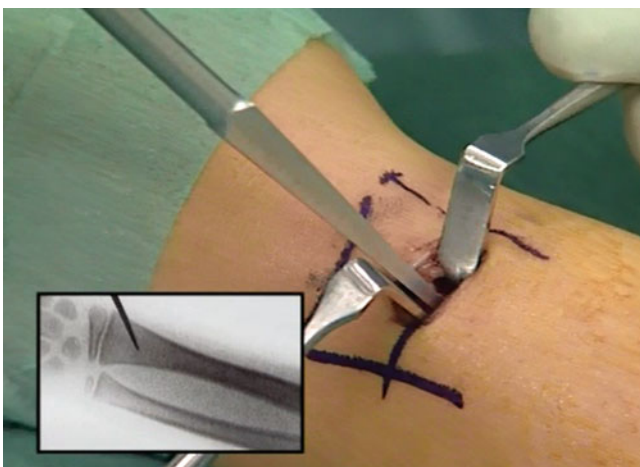


Fig. 7 Opening of the medullary canal with an awl under visual control

The well-precontoured nail is now inserted under visual control. The alignment of the nail tip should be checked under an image intensifier shot (Fig. 9).

In the next step, the nail is advanced under oscillating rotation up to the fracture; at this point it's important to rotate the fracture using the intensifier in a way that visualizes the most severe angulation/displacement of the fracture. The precontoured nail tip must be orientated to the displaced/angulated fracture fragment (Fig. 10).

Once the nail is correctly oriented, it is inserted into the radial head by gentle hammer blows. A single perforation of the physis for a better fixation of the nail in the fragment does not cause any growth disturbances.

In the next step, the arm is flexed, the forearm pronated, and at the same time the nail 180° rotated as shown in Fig. 11.

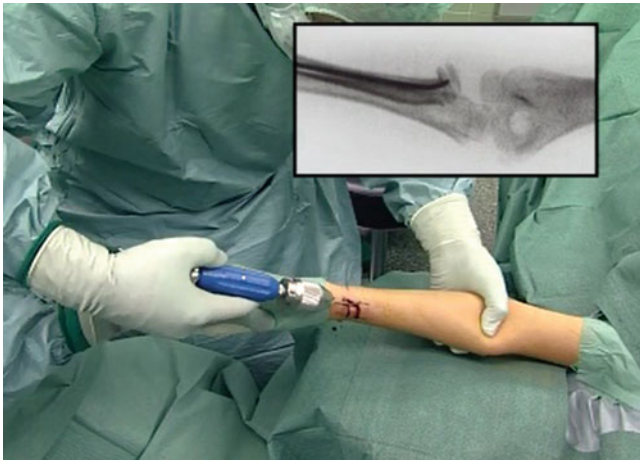


Fig. 10 The tip of the nail is now in the radial neck metaphysis; with the thumb an external pressure can help for reduction

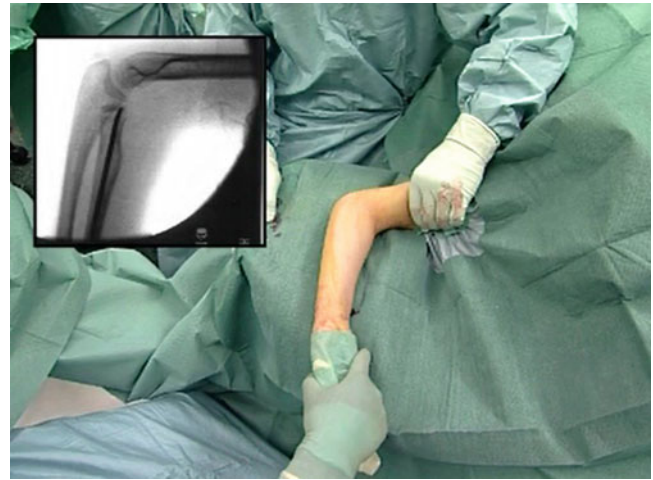


Fig. 13 Control of the reduction in lateral view



Fig. 11 By flexion of the elbow and simultaneous pronation of the forearm and rotation of the nail (clockwise or counterclockwise, depending on the side), the radial neck fracture is reduced



Fig. 14 Once the nail is in the correct position and the fracture perfectly reduced, the nail is cut

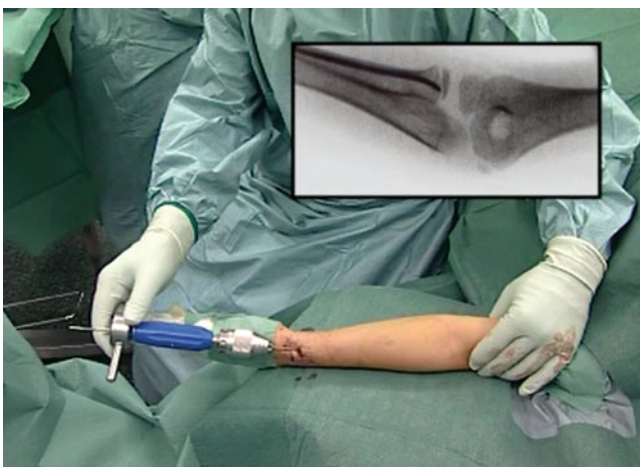


Fig. 12 Control of the reduction in AP and lateral view

Now the elbow/forearm is extended, and the reduction result should be visualized under the image intensifier; if the result is not perfect as shown in Fig. 12, ap projection and in Fig. 13, lateral view, this maneuver can be repeated. In the most cases, no more than two maneuvers result in a perfect reduction.

Once the result is radiologically perfect (and only perfect reduction should be accepted with this technique), the nail is shortened (Fig. 14). The end of the nail should be over the level of the retinaculum to prevent tendon irritation or even tendon ruptures (Fig. 15).

After closure of the wound, the last X-ray check is still under anesthesia; in case of an incorrect reduction, the nail can be pulled back after re-open the wound and the reduction maneuver repeated (Figs. 10 and 11).

The series of drawings shows again the different steps of the reduction maneuver (Fig. 16a–h).

7 Technical Pearls

It's important to shorten the nail in the correct length:

1. Use a cam rod cutter which avoids sharp ends (Fig. 14).

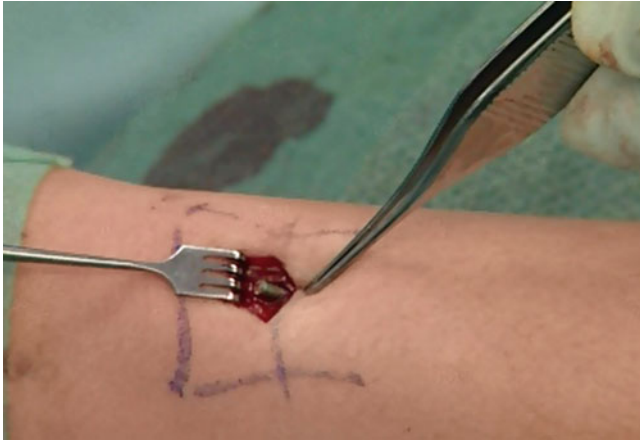


Fig. 15 To prevent irritation of the retinaculum or to avoid tendon rupture, it is recommended to leave the cut nail end above the level of the fascia

2. Leave the nail end over the retinaculum (Fig. 15); under the retinaculum there is a high risk for tendon irritation/rupture.
3. A longer nail end does not irritate the extension of the hand (even if there is a prominent bend) and facilitates the nail removal.
4. An end cap can be used to protect the tendons but is usually not necessary.

8 Outcome Radiographs

An immobilization in an arm sling for 3–4 weeks is sufficient, depending on the age of the child. After 4 weeks, the first follow-up X-ray was made, showing correct position and healing so that the child was allowed to return to sport (Fig. 17).

Figure 18 shows the full consolidation and perfect alignment. Nail removal is recommended and can now be planned, depending on local protocols.

No more controls were required; the child has asymmetrical range of motion and absolutely no restrictions.

Fig. 16 (a–h) Shows the different steps of indirect reduction in a kind of animation: (a) dislocated/angulated radial head; the main reason for this fracture is caused by the annular ligament which has the effect of a hypomochlion! (b) The nail is advanced in the radial medullary canal. (c) Now the nail has reached the fracture. (d) In the best projection of the fracture, the tip of the nail is orientated toward the displaced radial head. (e) Now the nail is hammered with gentle blows into the radial head. (f) Rotation of the nail. (g) Well-aligned radial neck. (h) All demonstrated in the complete forearm overview

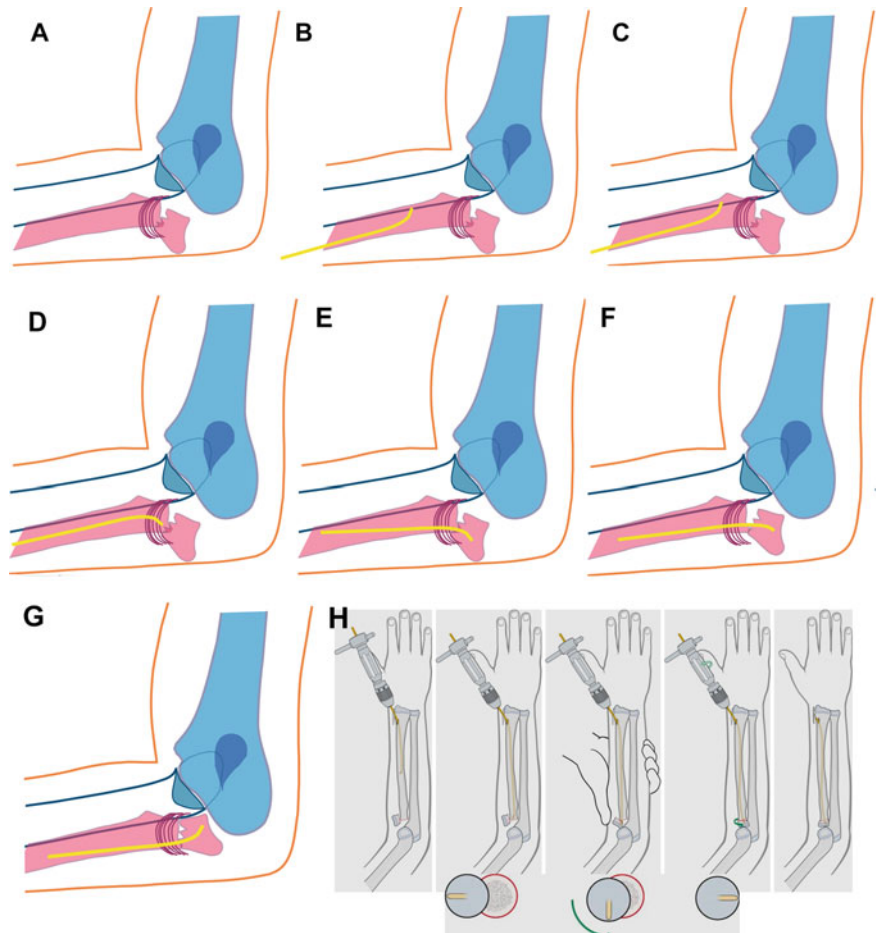




Fig. 17 1-month follow-up X-ray shows perfect alignment; sport is now allowed

9 Avoiding and Managing Problems

Depending on the child's activity and arm mobilization, the unrestricted use of the forearm was allowed.

For such an unproblematic fracture, no long-term follow-up is necessary. The parents are asked to return to the hospital if in a month's time, the arm cannot be normally used.

10 Cross-References

- [Midshaft Both Bone Forearm Fracture: Intramedullary Rod Fixation](#)



Fig. 18 Last X-ray control before nail removal; no further control visits or radiographs are required

References and Suggested Readings

- Basmajian HG, Choi PD, Huh K, Sankar WN, Wells L, Arkader A (2014) A Radial neck fractures in children: experience from two level-1 trauma centers. *J Pediatr Orthop B* 23(4):369–374
- Dietz HG, Schmittenbecher PP, Slongo TF, Wilkins KE (2006) AO manual of fracture management. Elastic stable intramedullary nailing (ESIN) in children. Thieme, Stuttgart
- Falciglia F, Giordano M, Aulisa AG, Di Lazzaro A, Guzzanti V (2014) Radial neck fractures in children: results when open reduction is indicated. *J Pediatr Orthop* 34(8):756–762
- Gonzalez-Herranz P, Alvarez-Romera A, Burgos J, Rapariz JM, Hevia E (1997) Displaced radial neck fractures in children treated by closed intramedullary pinning (Metaizeau technique). *J Pediatr Orthop* 17:325–331
- Klitscher D, Richter S, Bodenschatz K et al (2009) Evaluation of severely displaced radial neck fractures in children treated with elastic stable intramedullary nailing. *J Pediatr Orthop* 29:698–703
- Lascombe P (2006) Embrochage centromédullaire élastique stable. Elsevier, Masson, Issy-les Moulineaux

- Metaizeau JP, Lascombes P, Lemelle JL, Finlayson D, Prevot J (1993) Reduction and fixation of displaced radial neck fractures by closed intramedullary pinning. *J Pediatr Orthop* 13:355–360
- Schmittenebecher PP, Haevernick B, Herold A, Knorr P, Schmid E (2005a) Treatment decision, method of osteosynthesis, and outcome in radial neck fractures in children. *J Pediatr Orthop* 25:45–50
- Schmittenebecher PP, Haevernick B, Herold A, Knorr P, Schmid E (2005b) Treatment decision, method of osteosynthesis, and outcome in radial neck fractures in children: a multicenter study. *J Pediatr Orthop* 25:45–50
- Slongo T, Audigé L, Schlickewei W, Clavert JM, Hunter J (2006) Development and validation of the AO pediatric comprehensive classification of long bone fractures by the pediatric expert group of the AO foundation in collaboration with AO clinical investigation and documentation and the international association for pediatric traumatology. *J Pediatr Orthop* 26:43–49
- Slongo T, Audigé L, AO Classification Group (2007) AO Pediatric comprehensive classification of long bone fractures (PCCF). AO Publishing, Davos
- Vocke AK, von Laer L (1998) Displaced fractures of the radial neck in children: long-term results and prognosis of conservative treatment. *J Pediatr Orthop Part B* 7:217–222

Radial Neck Fracture: Operative Treatment (ESIN) “Joy-Stick” Technique

Theddy Slongo

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Abstract

In childhood, the majority of fractures around the proximal radius are radial neck fractures, according to the AO Pediatric Comprehensive classification (Slongo et al., J Pediatr Orthop 26:43–49, 2006; AO pediatric comprehensive classification of long bone fractures (PCCF). AO Publishing, Davos, 2007): 21r-M and 21r-E fractures. With the implementation of the ESIN method, the indication for closed reduction and stabilization has been significantly expanded. So we recommend treating only slightly displaced or absolutely stable fractures conservatively. Conservative treatment means that we do not perform an active reduction. The acceptable displacement depends on the age of the child and the remaining remodeling capacity. Tables 1 and 2 show the possible fracture pattern we recommend for operative treatment on one hand and

which needs an additional external reduction support by a “Joy-Stick” technique.

1 Brief Clinical History

A 10-year-old boy sustained injury from a road traffic accident. His arm got stuck between the car and his bicycle. The arm was compressed. The boy was transferred to a children’s hospital using an ambulance.

In the emergency room, we have seen a 10-year-old boy who was well-orientated and whose arm was fixed on a prefabricated splint. Sensibility and circulation were normal. There was severe swelling around the elbow and the proximal third of the forearm. Pronation and supination motion was blocked.

In addition, he had some skin lesions around both knees and the shoulder.

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2 Preoperative Clinical Photos and Radiographs

Due to the clinical examination and the case history, an AP and lateral x-ray of the elbow and the forearm was performed.

Figure 1 shows the AP and lateral x-ray of the elbow with a fully displaced radial neck fracture (21–M/3.1 III) with a very short metaphyseal segment. In principle the radial head fragment is located on the radial side of the proximal radius.

The complete forearm x-ray didn't show any other fracture or lesion.

3 Preoperative Problem List

As there were no other skeletal injuries and the neurovascular situation was normal, we planned, according to our algorithm of Type II and III fractures, to operate on this fracture the next day.

Table 1 Graphic drawings according the AO Pediatric Comprehensive Classification for operative treatment of metaphyseal fractures which need Joy-Stick technique for additional help for external reduction

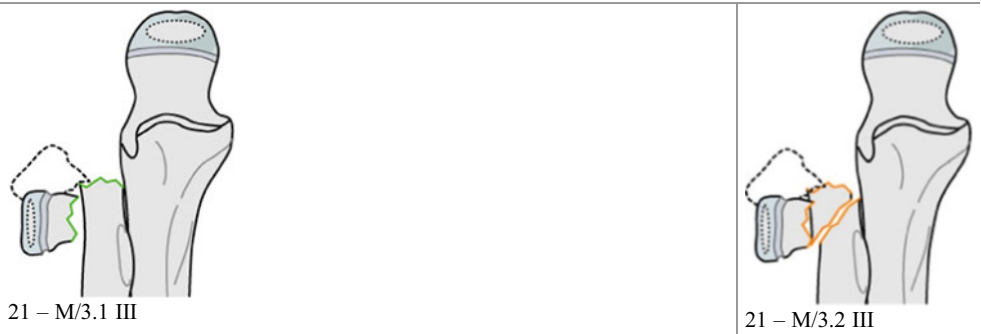


Table 2 Graphic drawing according to the AO Pediatric Comprehensive Classification for operative treatment of epiphyseal fractures which need Joy-Stick technique for additional help for external reduction

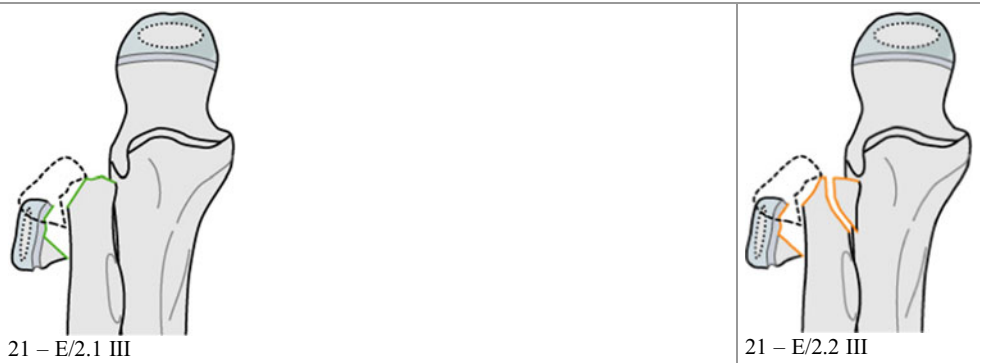


Fig. 1 AP and lateral x-ray of the elbow of a 10-year-old boy with nearly completely displaced radial neck fracture; recognize that the radial head is on the radial side of the radius

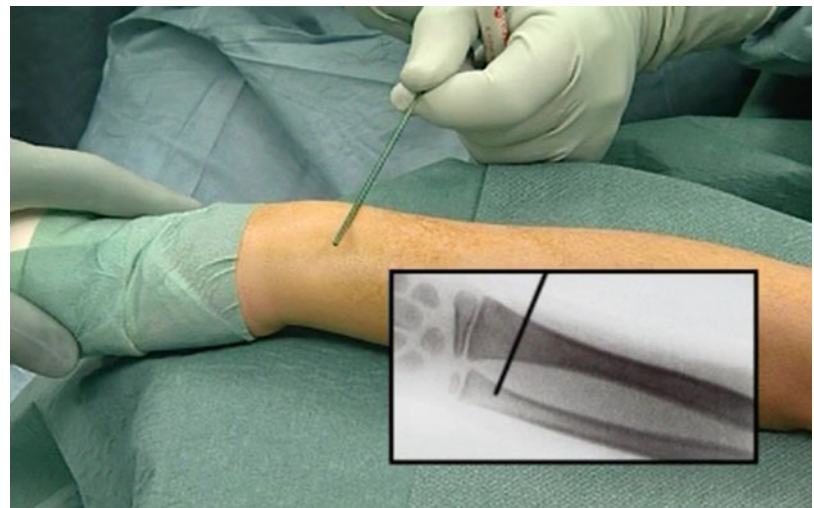


This fracture is never an emergency surgery, and the child profits from optimizing resources with experienced surgeon and team during regular hours of operation.



Fig. 2 Position on the sterile-draped forearm direct on the camera side of the image intensifier

Fig. 3 Determination of the level of the entry point over Lister's tubercle under image intensifier control



4 Treatment Strategy

Overall Goal: To reduce this fracture from type III to type II by using Joy-Stick and reduce it by using ESIN technique to a type I fracture or a complete anatomical position.

A completely displaced radial neck fracture must not be the indication for an open reduction and open internal fixation. Even completely displaced fractures are still a perfect indication to use the closed, indirect reduction and ESIN (elastic stable intramedullary nailing) technique. Additional tricks are often necessary.

Before we can reduce the fracture with the tip-of-the-well pre-bent nail, we have to push the head fragment into a better position; once the neck fragment is pushed back to an acceptable position, the nail tip can reach the fragment; the same reduction procedure as in type II fractures is then used (Figs. 9, 10, and 11).

The presence of a skilled surgeon who has an experience in performing ESIN technique is important. On the other hand, as this fracture can be scheduled during regular operating hours, it allows for "teaching" this procedure, assisted by a ESIN-experienced surgeon.

5 Basic Principles in the Treatment

See Tables 1 and 2.

The basic principles of this treatment are the following:

1. Insertion of an elastic nail 2.0 mm or 2.5 mm, depending on the age/size of the child and the distal metaphysis of the radius.



Fig. 4 3-cm long transverse skin incision along the skin lines



Fig. 7 Pre-bending of the first 5 cm of the nail for a better advancement and reduction of the radial neck/head

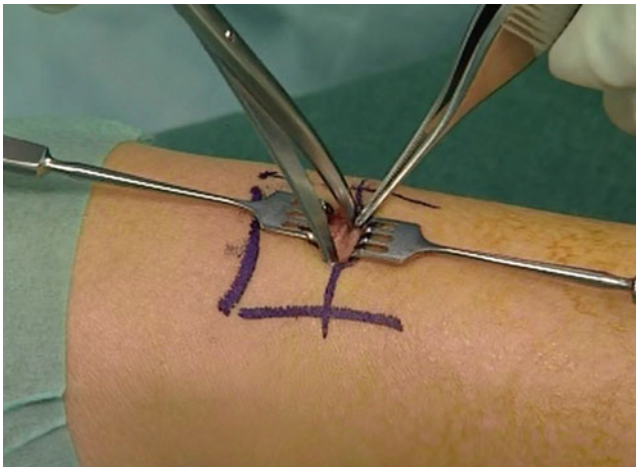


Fig. 5 Blount dissection of the subcutaneous layers and the tendons



Fig. 8 Insertion of the nail under visual control; the alignment of the nail curve must be checked under image intensifier control

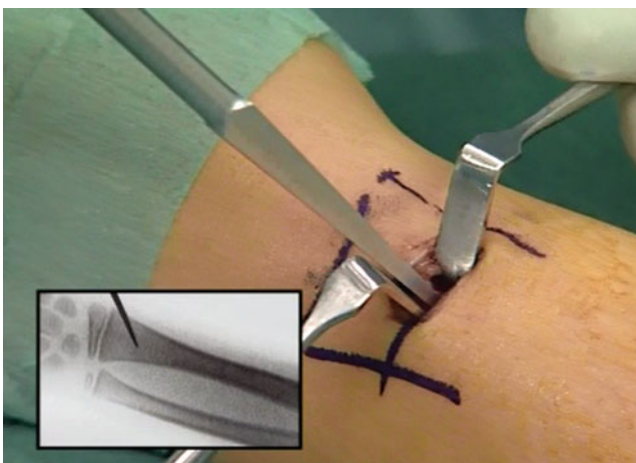


Fig. 6 Opening of the medullary canal with an awl under visual control

2. Advancement of the nail to the fracture line.
3. Percutaneous insertion of a 1.6 or 2.0 mm wire to push the radial head into a better position.
4. Orientation of the nail tip toward the biggest angulation of the radial head and insertion of the nail tip into the better-positioned radial head.
5. A combination of external pressure to the radial head and internal reduction of the radial head by rotating the nail.
6. Fixation of the reduced radial head.
7. Free functional movement should be achieved
8. Plaster-free mobilization of the forearm postoperative

Fig. 9 In this situation the elastic nail cannot reach the neck fragment; therefore the "Joy-Stick" technique is used.

Recognize the lateral intact periosteum where the remaining vessels for the head are located; by pushing the radial head with the tip of the K-wire, damage to the vessels can be avoided!

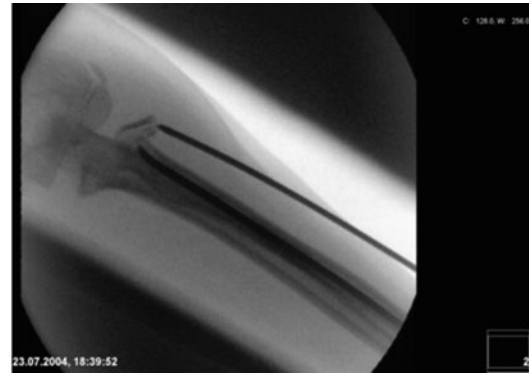
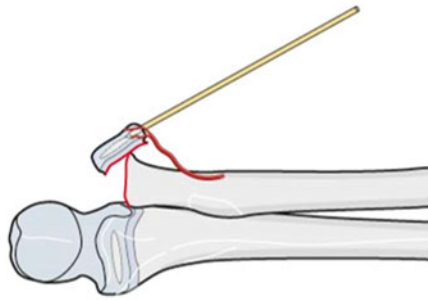


Fig. 10 Now the radial head is in a good position for the elastic nail to perform the indirect reduction as shown in chapter ► "Radial Neck Fractures: Operative Treatment (ESIN)"

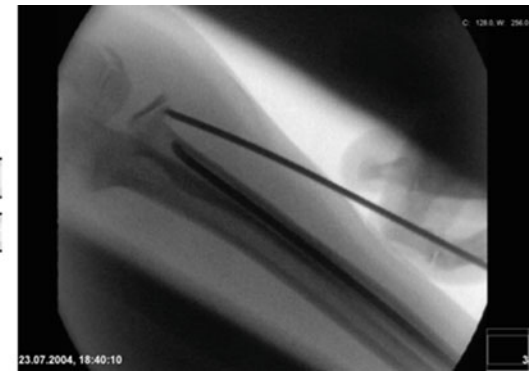
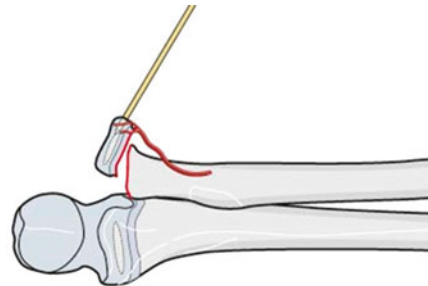


Fig. 11 Now the radial head is in a good position for the elastic nail to perform the indirect reduction as shown in this detailed view

6 Images During Treatment

After correct positioning of the injured forearm on the arm table or as we do, direct on the image intensifier (Fig. 2), we must identify the distal entry point. We recommend the use of Lister's tubercle approach or the traditional dorso-radial approach. Figure 3 shows the level of the skin incision, along the skin line transverse. This level should be checked under the image intensifier.

Skin incision is then performed as shown in Fig. 4, and a blunt dissection up to Lister's tubercle, while respecting the retinaculum and the tendons, is performed as demonstrated in Fig. 5.

Figure 6 shows the position of the awl, direct on the bone; a blind approach should be avoided. This entry point and the correct position of the awl must be checked under the image intensifier.

In the next step, the proximal third of the nail should be pre-bent (pre-contoured) as shown in the pictures. This facilitated the nail insertion and the indirect head reduction once the nail has reached the radial head (Fig. 7).

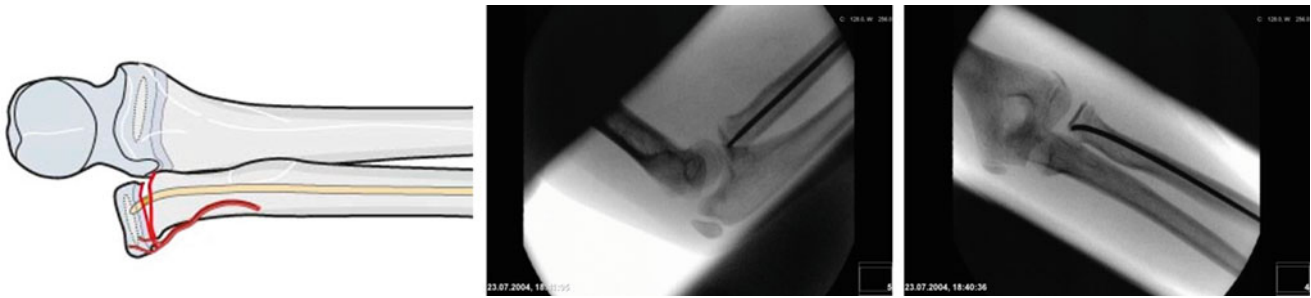


Fig. 12 Now the fracture is anatomically reduced and the tip of the nail is in the radial head. A single perforation of the physis does not cause any growth problems



Fig. 13 This intraoperative image intensifier series show again the reduction process



Fig. 14 What we should avoid to reduce the head using a “Kapandji technique” is again demonstrated in this figure. Failure to avoid results to a high risk of avascular necrosis of the radial head

The tip-of-the-well pre-bent nail is now inserted under visual control. Check the alignment of the nail tip under one image intensifier shot (Fig. 8).

In the next step, the nail is advanced under oscillating rotation up to the fracture.

Now a K-wire is inserted through the skin at distal angle in a way that the sharp trocar tip of the K-wire can push the radial head in a better position as shown in Figs. 9 and 10.

At this point it is important to rotate the nail tip under the image intensifier toward the displaced/angulated fracture (Fig. 11).

Figure 12 shows now the reduction of the radial head in an anatomical position.

The image intensifier series in Fig. 13 show again the different steps.

As demonstrated in Fig. 14, in a “Kapandji technique,” we should avoid sticking the K-wire in the fracture gap. We have to recognize that exactly at this point, we have the remaining blood supply of the radial head. This position/technique of reduction has a high risk of blood supply damage of the radial head, resulting in an avascular necrosis, see Figs. 14 and 15.

Once the nail is correctly orientated, it is inserted into the radial head through gentle hammer blows. A single perforation for a better grip of the nail doesn’t cause any growth disturbances.

In the next step, the arm is flexed, the forearm is pronated, and the nail is rotated by 180° as shown in Fig. 16.

Now we extend the elbow/forearm and check our reduction result under the image intensifier; if the result is not perfect as expected, this maneuver can be repeated. In most

Fig. 15 Figure 9 demonstrates again the correct reduction using a K-wire

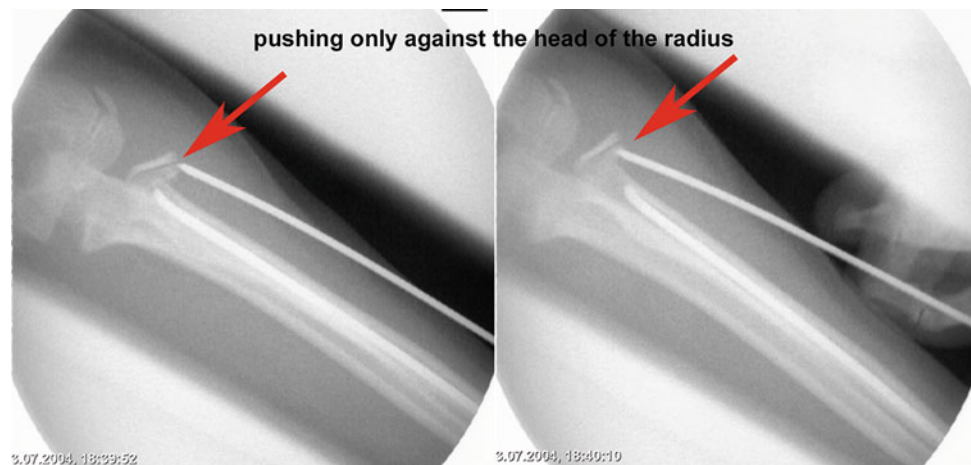


Fig. 16 By flexion of the elbow and simultaneous pronation of the forearm and rotation of the nail (clockwise or counterclockwise, depending on the side), the radial neck fracture is reduced



Fig. 17 Once the nail is in the correct position and the fracture perfectly reduced, the nail is cut

cases, in the second maneuver, a perfect alignment can be achieved.

Once the result is radiologically perfect (and we should accept only perfect reduction with this technique), the nail is shortened (Fig. 17).

After the wound is closed, the last x-ray check is still under anesthesia; in case of an incorrect reduction, the nail has to be pulled back and the reduction maneuver repeated.

2. Leave the nail end over the retinaculum; under the retinaculum, there is a high risk for tendon irritation/rupture.
3. Even a longer nail end does not irritate the extension of the hand (even if you see a prominent buckle) and facilitates the nail removal.

The series of drawings show again the different steps of the reduction maneuver (Fig. 18a–h).

7 Technical Pearls

It is important to shorten the nail in the correct length:

- Tips:
 1. Use a tube-within-a-tube style cutter which avoids sharp ends.

8 Outcome Radiographs

Immobilization provided by an arm sling for 3–4 weeks is sufficient, depending on the age of the child. After 4 weeks, the first follow-up x-ray was made, showing a correct position and healing, so the child was allowed to return to sport (Figs. 19 and 20).

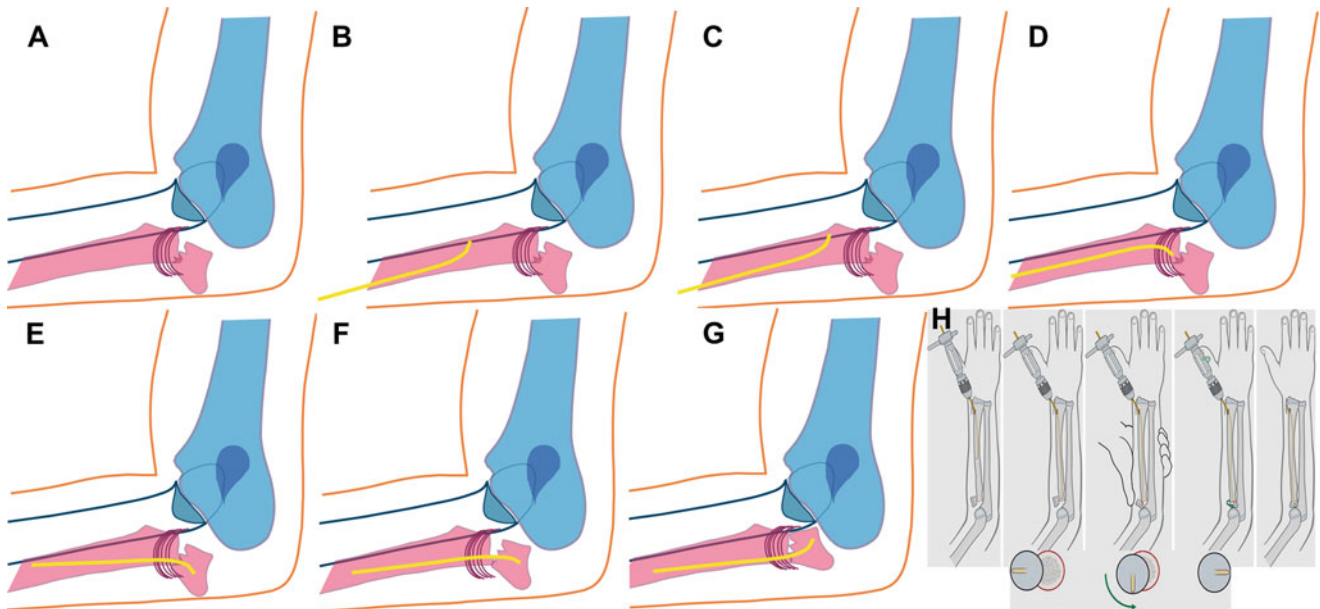


Fig. 18 (a–h) Shows the different steps of indirect reduction through an animation: (a) dislocated/angulated radial head; the main reason for this fracture caused in the annular ligament which has the effect of a hypomochlion! (b) The nail is advanced in the radial medullary canal. (c) Now the nail has reached the fracture. (d) In the best projection of the

fracture, the tip of the nail is orientated toward the displaced radial head. (e) Now the nail is inserted into the radial head through gentle hammer blows. (f) Rotation of the nail. (g) Well-aligned radial neck. (h) All demonstrated in the complete forearm overview

Fig. 19 The postoperative x-ray the next day shows again a perfect alignment of the fracture



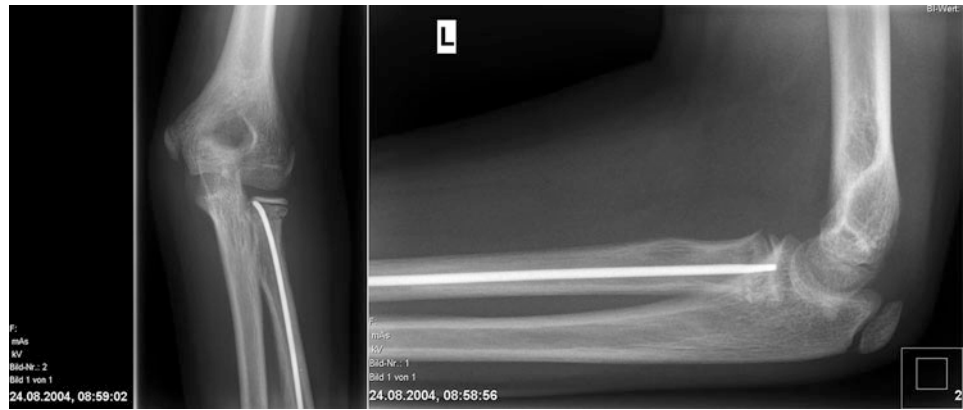
The next control should be planned 4–5 months postoperative; at this moment, nail removal can be planned.

No more controls were required; the child has asymmetrical range of motion and absolutely no restrictions.

9 Avoiding and Managing Problems

Depending on the child's activity and arm mobilization, unrestricted use of the forearm was allowed.

Fig. 20 In the follow-up x-ray 5 weeks postoperative, the healing is not yet complete, but we allowed the child to go back to sport



In our hands, for such a problematic fracture, no long-term follow-up is planned. The parents are requested for a visit if in 1 month the arm cannot be used normally.

10 Cross-References

- [Midshaft Both Bone Forearm Fracture: Intramedullary Rod Fixation](#)

References and Suggested Readings

- Basmajian HG, Choi PD, Huh K, Sankar WN, Wells L, Arkader A (2014) A radial neck fractures in children: experience from two level-1 trauma centers. *J Pediatr Orthop B* 23(4):369–374
- Dietz HG, Schmittenbecher PP, Slongo TF, Wilkins KE (2006) AO manual of fracture management. Elastic stable intramedullary nailing (ESIN) in children. Thieme, Stuttgart
- Falciglia F, Giordano M, Aulisa AG, Di Lazzaro A, Guzzanti V (2014) Radial neck fractures in children: results when open reduction is indicated. *J Pediatr Orthop* 34(8):756–762
- Gonzalez-Herranz P, Alvarez-Romera A, Burgos J, Rapariz JM, Hevia E (1997) Displaced radial neck fractures in children treated by closed intramedullary pinning (Metaizeau technique). *J Pediatr Orthop* 17:325–331
- Klitscher D, Richter S, Bodenschatz K et al (2009) Evaluation of severely displaced radial neck fractures in children treated with elastic stable intramedullary nailing. *J Pediatr Orthop* 29:698–703
- Lascombe P (2006) Embrochage centromédullaire élastique stable. Elsevier, Masson, Issy-les Moulineaux
- Metaizeau JP, Lascombes P, Lemelle JL, Finlayson D, Prevot J (1993) Reduction and fixation of displaced radial neck fractures by closed intramedullary pinning. *J Pediatr Orthop* 13:355–360
- Schmittenbecher PP, Haevernick B, Herold A, Knorr P, Schmid E (2005a) Treatment decision, method of osteosynthesis, and outcome in radial neck fractures in children. *J Pediatr Orthop* 25:45–50
- Schmittenbecher PP, Haevernick B, Herold A, Knorr P, Schmid E (2005b) Treatment decision, method of osteosynthesis, and outcome in radial neck fractures in children: a multicenter study. *J Pediatr Orthop* 25:45–50
- Slongo T, Audigé L, Schlickewei W, Clavert JM, Hunter J (2006) Development and validation of the AO pediatric comprehensive classification of long bone fractures by the pediatric expert group of the AO foundation in collaboration with AO clinical investigation and documentation and the international association for pediatric traumatology. *J Pediatr Orthop* 26:43–49
- Slongo T, Audigé L, AO Classification Group (2007) AO pediatric comprehensive classification of long bone fractures (PCCF). AO Publishing, Davos
- Vocke AK, von Laer L (1998) Displaced fractures of the radial neck in children: long-term results and prognosis of conservative treatment. *J Pediatr Orthop Part B* 7:217–222

Radial Neck Fractures: Operative Treatment “Mini-Open” and ESIN

Theddy Slongo

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Abstract

In childhood, the majority of fractures around the proximal radius are radial neck fractures, according the AO Pediatric classification (Slongo et al. 2006/2007) 21r – M and 21r – E fractures. 95% of all fractures are “Flexion Fractures” that means the radial head is displaced in flexion towards the radial metaphysis. In very rare cases the radial head fractures flips backwards, in extension. The theory of the patho-mechanism can be, that during an axial trauma to the elbow the radius makes a subluxation or a luxation. At this moment a metaphyseal fracture happens but without displacement. In a second step the radius shaft goes back distally and the damaged metaphysis breaks, and the radial head flips backwards.

Sometimes the dorsally flipped radial head fragment is difficult to see. In such a fracture the normal indirect

reduction technique with the ESIN method is not possible. Therefore an open reduction is required.

To avoid vascular damage of the radial head a combined approach is recommended; dorsal mini-open visualization of the radial head, by using the Joy-stick technique, the radial head is gently pushed distally so that the head fragment can be captured with the elastic nail and definitively reduced and fixed in the traditional ESIN technique.

1 Brief Clinical History

An 8-year-old boy had a ski injury. The mother reported that he felt on the outstretched arm. The boy had severe pain and the arm was angulated. She said that she was thinking the elbow was dislocated. The rescue service was called. The boy received pain medication and pain and axial traction was applied followed by a splint the arm.

In the emergency department the boy was oriented and sensibility and circulation was normal. Severe swelling

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around the elbow and the proximal third of the forearm was noted. Pro- and supination was not possible because of severe pain.

2 Preoperative Clinical Photos and Radiographs

An AP and lateral x-ray of the elbow and the forearm was performed.

Figure 1 shows this very special condition in a drawing.

Figure 2 shows the AP and lateral x-rays of the elbow with a fully displaced radial neck fracture (21 – M/3.1 III). Initially the diagnosis was not clear because the dorsally flipped radial

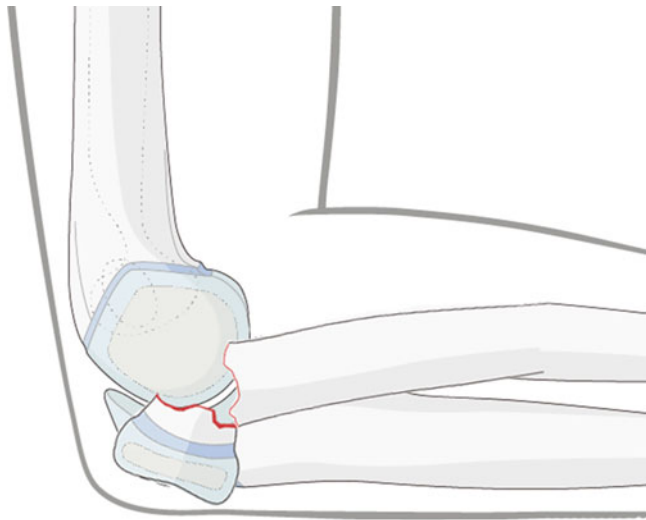
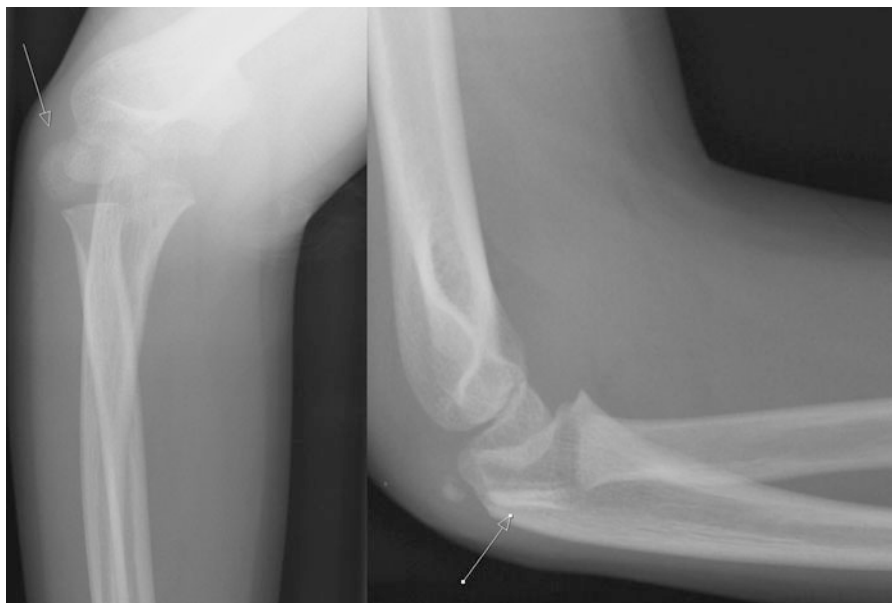


Fig. 1 Graphical illustration of this special radial neck fracture; extension type with dorsal flipped radial head

Fig. 2 Incision for mini – open approach to the radial head; try to avoid to cut in the annular ligament



3 Preoperative Problem List

- As this type of radial neck fracture is completely different, we have to think about an alternative, but also gentle treatment.
- This type of fracture has a high risk of avascular necrosis because the periosteum could be fully, circumferentially ruptured.
- On the other hand, with the classical ESIN technique the fragment cannot be reduced or manipulated.
- This fracture is never an emergency surgery and the child profits from a good and experienced surgeon.

4 Treatment Strategy

The indication for a Mini-Open reduction and internal fixation with ESIN Technique is shown in Table 1.

The main goal is to push back the flipped fragment in a better position and create a typical flexion fracture so that the radial head can be caught and reduced in a typical ESIN technique.

To avoid additional damage of the periosteum and the remaining blood supply we should avoid the classical approach to the proximal radius and radial head, respectively. The best way to get to the flipped radial head would be through a radial short incision on the most proximal side of the capsule insertion. Figure 3 shows our approach. This incision allows a good view to the dorsal joint over the radial

Table 1 Graphic drawings according to the AO pediatric classification for operative treatment metaphyseal fractures which needs an additional external reduction by Joy-Stick technique

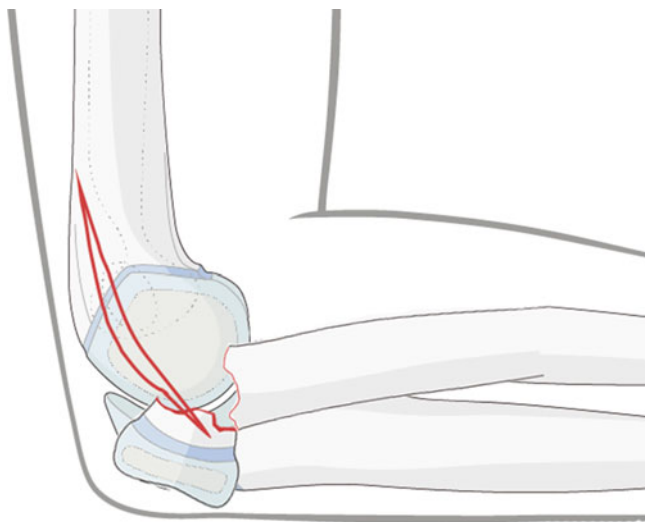


Fig. 3 The wound is more open to dorsal aspect

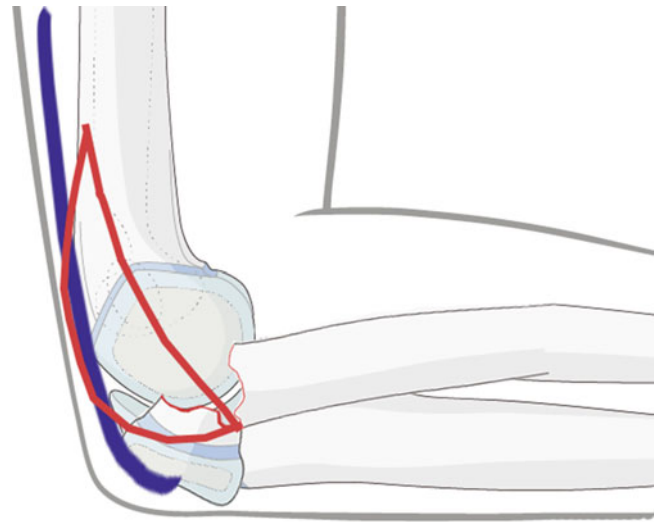


Fig. 4 The pre-contoured K-wire or the dental hook is placed on the radial head to push it back

capitellum, so that we can push back the radial head in front of the capitellum.

Before we can reduce the fracture with the tip of the sharply pre-bent nail-tip, we have to push the head fragment in a better position; once the neck fragment is pushed back to an acceptable position, that the nail tip can reach this fragment, the reduction procedure is the same as in a type II fracture (Figs. 4, 5, 6 and 7).

It's important that a skilled surgeon who is proficient in this ESIN technique is present. On the other hand, as this fracture can be scheduled in the normal program, it allows to do this as a “teaching” operation, assisted by an ESIN-experienced surgeon.

For this operation, an image intensifier is mandatory. In addition, the adequate instruments and implants (nails 2.0 mm or 2.5 mm) and a 1.6 mm or 2 mm K-wire must be available. As the irradiation can be theoretically more, we recommend performing this operation directly on the camera side of the intensifier. (the arm does not reflect a lot of irradiation).

5 Basic Principles in the Treatment

The basic principles of this treatment are the following:

1. Good visualization of the fracture under image intensifier
2. Apply a sterile tourniquet
3. Now prepare the TEN for the typical insertion (we recommend to use the Lister's tubercle approach) as shown in case 4
4. Advance the nail tip up to the fracture line (chapter ► [Radial Neck Fractures: Operative Treatment \(ESIN\)](#))
5. Now short dorso-lateral incision as shown in Fig. 3.
6. Visualization of the flipped radial head fragment
7. With the help of a 1.6 mm K-wire which is bent at the tip as demonstrated in Fig. 4 (or better use a dental hook) lift up and push back the radial head towards the main radial fragment. *Trick:* Try to dislocate the elbow again so that the radial shaft comes under the Capitellum, in this position it's much easier and safer

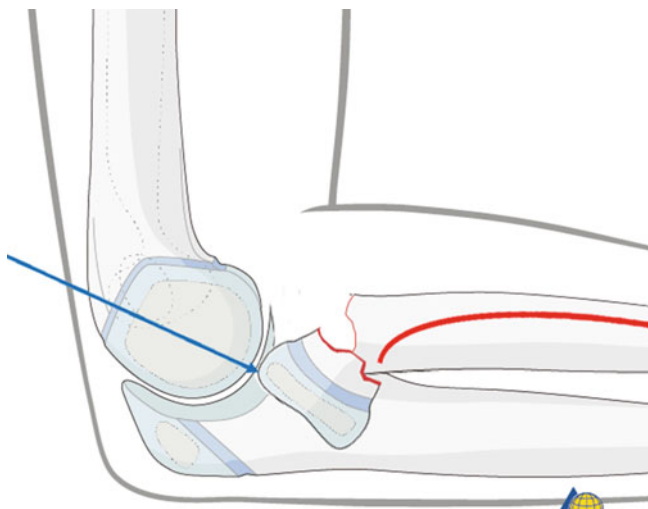


Fig. 5 This drawing shows the partially reduced and pushed back radial head. The titanium elastic nail (TEN) is in a “waiting” position at the level of the fracture

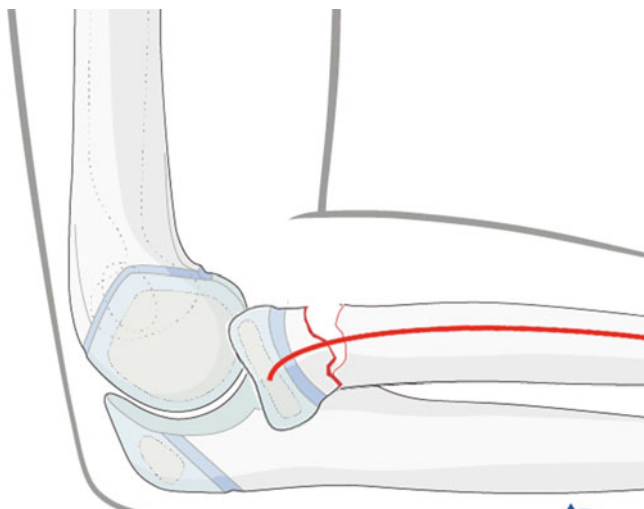


Fig. 7 The radial head is well caught and by typical rotation the head is going to be reduced

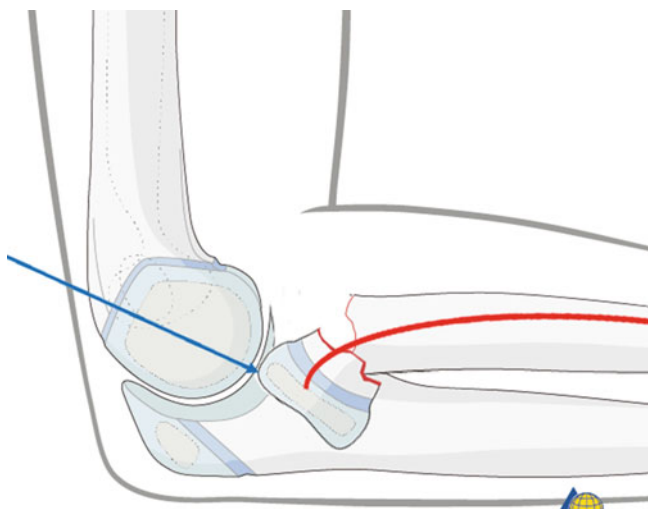


Fig. 6 By still holding the neck fragment in a partial reduced position, the TEN is now advanced into the head fragment

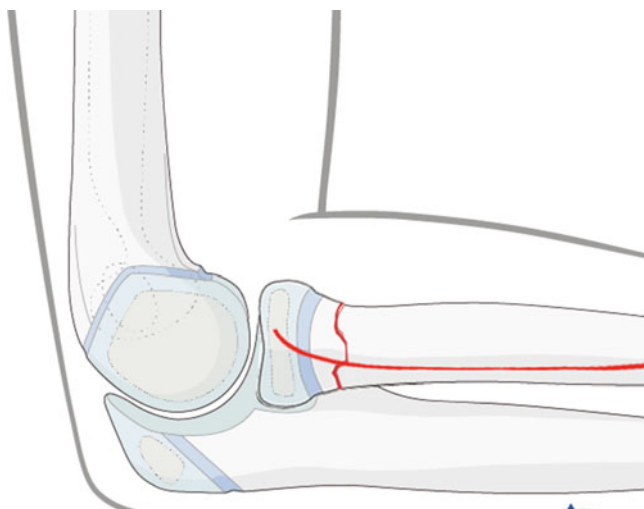


Fig. 8 Perfect reduction of the head by rotation of the TEN 180°

to push back the radial head. Then by pressing the radial head towards the main fragment, reduce the elbow again.

8. Figure 5 shows the situation after pushing back the radial head and reposition of the elbow
9. Now the positioned nail (which was in a “waiting position”) is inserted in the head fragment by gentle hammer blows. The head must still be fixed/pushed by the K-wire, otherwise with the TEN the head flips back (Fig. 6).
10. By the typical rotation maneuver the head is definitively reduced (Figs. 7 and 8).
11. Free functional movement should be achieved
12. Plaster free mobilization of the forearm postoperative

6 Images During Treatment

Positioning of the sterile draped forearm on the image intensifier (Fig. 9)

Identification of the distal entry point. Today we recommend to use the Listers Tubercle approach or the traditional dorso-radial approach. Figure 10 shows the level of the skin incision, today along the skin line transverse. This level should be checked under intensifier.

Preparation of the Nail by pre-bending of the first 5 cm of the nail to create a good “memory” of the nail (Fig. 11).

Figure 12 shows the position of the awl, direct on the bone, a blind approach should be avoided. This entry point



Fig. 9 Clinical situation and setting of the forearm, direct on the image intensifier

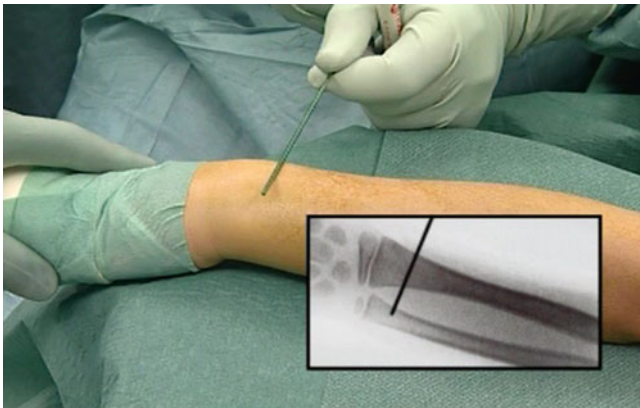


Fig. 10 Under image intensifier the distal entry-point is marked

and the correct position of the awl must be checked under intensifier.

The well pre-bent nail is now inserted under visual control. Check the alignment of the nail tip under one image intensifier shot (see chapter ► [“Radial Neck Fractures: Operative Treatment \(ESIN\)”](#)).



Fig. 11 The TEN is pre-bent in the first 5–6 cm from the tip; this creates a kind of “memory-effect” within the nail. So, the radial head fragment can better be manipulated

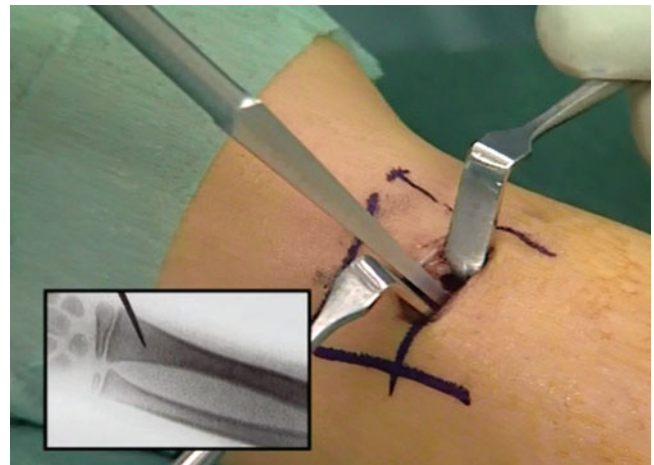


Fig. 12 Opening of the metaphysis over Lister’s Tubercle under view



Fig. 13 Typical maneuver for indirect reduction by rotating the nail and at the same time full flexion of the elbow



Fig. 14 Positioning of the K-wire for pushing back of the radial head as shown in Fig. 4



Fig. 15 Under continuous pressure with the K-wire against the radial head, the TEN is advanced into the fragment with gentle hammer blows



Fig. 16 Shows the intra-operative result; this is also the post-operative documentation

In the next step the nail is advanced under oscillating rotation up to the fracture (Fig. 13);

Figures 14 and 15 show the situation under image intensifier and the drawing in Fig. 5 shows the position of the K-wire again.

In the next step the arm is flexed, the forearm pronated and at the same time the nail 180° rotated as shown in see chapter ► **“Radial Neck Fractures: Operative Treatment (ESIN)”**.

Now we extend the elbow/forearm and check our reduction result under image intensifier; if the result is not perfect as expected, this manoeuvre can be repeated. In the most cases in the second manoeuvre a perfect alignment can be achieved. Figure 16 shows the intraoperative documentation of the reduction and fixation result.

Once the result is radiological perfect (and we should accept only perfect reduction with this technique) the nail is shortened (Fig. 17; chapter ► **“Radial Neck Fractures: Operative Treatment (ESIN)”**).

7 Technical Pearls

It's important to shorten the nail in the correct length:

Tips

1. Use a bolt cutter which avoids sharp ends
2. Leave the nail-end over the retinaculum; under the retinaculum there is a high risk for tendon irritation/rupture
3. Even a longer nail end does not irritate the extension of the hand (even you see a prominent buckle) and facilitates the nail removal.

Fig. 17 x-ray control after 4 weeks, shows a perfect alignment of the fracture and a beginning of the consolidation; sport is now allowed



Fig. 18 Follow up x-ray after 3 months after nail removal; full consolidation and perfect function was achieved



After closure of the wound the last x-ray check is still under anesthesia; in case of an incorrect reduction, the nail has been pulled back and the reduction manoeuvre has to be repeated.

8 Outcome Radiographs

An immobilization in an arm sling for 3–4 weeks is sufficient, depending on the age of the child. After 4 weeks, the first follow-up x-ray was made, showing a correct position and healing so that the child was allowed to return to sport (Fig. 17).

The next control radiograph should be planned 2 months postoperatively, at this moment, nail removal can be planned.

Figure 18 shows the absolutely normal situation and anatomical reduction, no signs of AVN at 3 Months after nail removal.

9 Avoiding and Managing Problems

Depending on the child's activity and arm mobilization the unrestricted use of the forearm was allowed.

Fig. 19 These two x-rays show two complications as a result of too extensive preparation and insufficient reduction/fixation

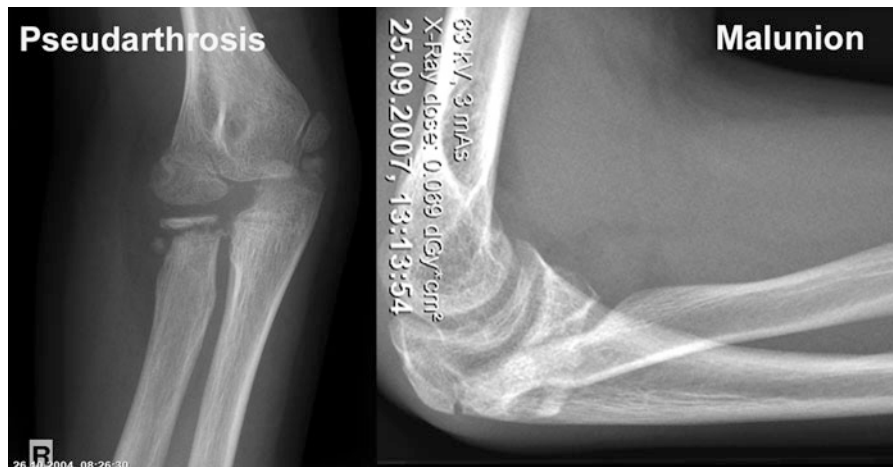


Fig. 20 This clinical picture demonstrates a too extensive exposure, direct over the critical zone. The x-ray on the right in Fig. 19 is of this patient

In our hand, for such an unproblematic fracture, no long-term follow-up is planned. The parents are requested for a visit if in 1 month the arm is not normally used.

We get a lot of such cases from outside with severe complications such as AVN or severe mal-alignment or pseudarthrosis as shown in Fig. 19. When we are looking at the scar or reading the operation protocol, we see that the most of the surgeons made a less than ideal incision and too extensive exploration (Fig. 20).

10 Cross-References

► Radial Neck Fractures: Operative Treatment (ESIN)

References and Suggested Reading

- Basmajian HG, Choi PD, Huh K, Sankar WN, Wells L, Arkader A (2014) Radial neck fractures in children: experience from two level-1 trauma centers. *J Pediatr Orthop B* 23(4):369–374
- Dietz HG, Schmittenbecher PP, Slongo TF, Wilkins KE (2006) AO manual of fracture management. In: Elastic Stable Intramedullary Nailing (ESIN) in children. Thieme, Stuttgart
- Falciglia F, Giordano M, Aulisa AG, Di Lazzaro A, Guzzanti V (2014 Dec) Radial neck fractures in children: results when open reduction is indicated. *J Pediatr Orthop* 34(8):756–762
- Gonzalez-Herranz P, Alvarez-Romera A, Burgos J, Rapariz JM, Hevia E (1997) Displaced radial neck fractures in children treated by closed intramedullary pinning (Metaizeau technique). *J Pediatr Orthop* 17:325–331
- Klitscher D, Richter S, Bodenschatz K et al (2009) Evaluation of severely displaced radial neck fractures in children treated with elastic stable intramedullary nailing. *J Pediatr Orthop* 29:698–703
- Lascombe P (2006) Embrochage centromédullaire élastique stable. Elsevier, Masson, Issy-les Moulineaux
- Metaizeau JP, Lascombes P, Lemelle JL, Finlayson D, Prevot J (1993) Reduction and fixation of displaced radial neck fractures by closed intramedullary pinning. *J Pediatr Orthop* 13:355–360
- Schmittenbecher PP, Haevernick B, Herold A, Knorr P, Schmid E (2005) Treatment decision, method of osteosynthesis, and outcome in radial neck fractures in children: a multicenter study. *J Pediatr Orthop* 25:45–50
- Slongo T, Audigé L, Schlickewei W, Clavert JM, Hunter J (2006) Development and validation of the AO pediatric comprehensive classification of long bone fractures by the pediatric expert group of the AO foundation in collaboration with AO clinical investigation and documentation and the international association for pediatric traumatology. *J Pediatr Orthop* 26: 43–49
- Slongo T, Audigé L, AO Classification Group (2007) AO Pediatric comprehensive classification of long bone fractures (PCCF). AO Publishing, Davos
- Vocke AK, von Laer L (1998) Displaced fractures of the radial neck in children: Long-term results and prognosis of conservative treatment. *J Pediatr Orthop Part B* 1(7):217–222

Radial Neck Fracture: Open Reduction

Laura Gill

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Abstract

Radial neck fractures account for 5–10% of all elbow injuries and are associated with concomitant injuries in 30–50% cases. The treatment algorithm for these fractures generally involves a graduated approach from closed to percutaneous and finally open methods. Outcomes of open treatment may be unpredictable, and it is generally considered a last resort as it is thought to be associated with worse outcomes. However, fractures requiring open treatment tend to be more severe and it is difficult to determine the cause of the outcome. In patients with severe displacement, planned open treatment should be considered to minimize iatrogenic trauma to the tissues. This chapter discusses indications and open treatment of radial neck fractures.

1 Brief Clinical History

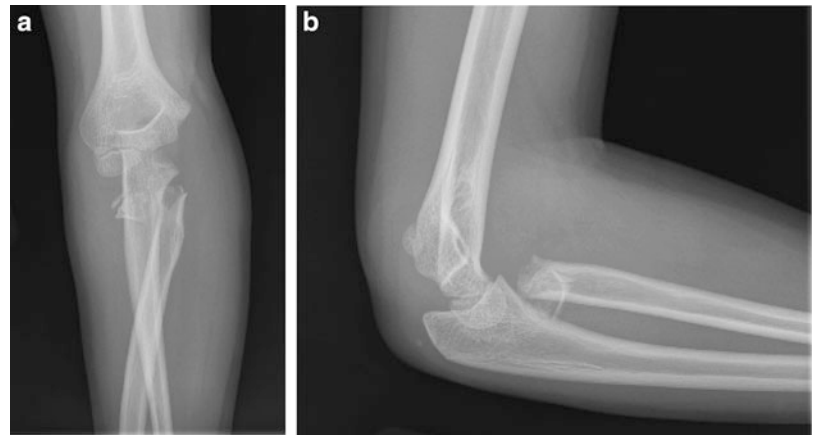
A 9-year-old right-hand dominant healthy female fell of the uneven bars at gymnastics onto her outstretched right upper extremity. She presented to the Emergency Department (ED) and was noted to have gross deformity and swelling to the right elbow. Her motor and sensory functions and vascular status were intact. Imaging revealed a 100% displaced radial neck fracture and a nondisplaced olecranon fracture (Fig. 1a, b). A failed attempt at closed reduction was performed in the ED, and she was placed in a long-arm splint and scheduled for operative intervention, closed vs open reduction and percutaneous pinning. Intraoperatively there was a failed single attempt at closed reduction, and when opened the radial head and neck were noted to be displaced medial to the coronoid and were largely stripped of soft tissue.

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Fig. 1 (a) AP radiograph demonstrating complete/100% displacement of the radial head and neck medially. (b) There is anterior subluxation of the shaft of the radius



2 Preoperative Clinical Photos and Radiographs

See Fig. 1a, b.

3 Preoperative Problem List

1. Severely displaced radial neck fracture
2. Associated olecranon fracture
3. Failed attempt at closed reduction in the ED

4 Treatment Strategy

Open reduction and internal fixation (ORIF) of radial neck fractures is generally indicated after a failed attempt to achieve a satisfactory reduction under general anesthetic. Acceptable limits of reduction are those with angulation $\leq 30^\circ$ and 2 mm translation with full pronation and supination (Pring 2012). Some authors may accept $30\text{--}50^\circ$ angulation in younger children, <10 years, where the remodeling potential is great, but this is controversial.

Open reduction is more likely in patients with more severe displacement at presentation, older children and those with higher body mass index (BMI) (Zimmerman et al. 2013).

Indications for open reduction include

1. Open fractures
2. Fractures displaced $>100\%$ or there is no contact between the neck and radial metaphysis
3. Angulation $>45\text{--}50^\circ$ or more than 30% displacement after failed closed reduction or manipulation by percutaneous methods (k-wires, intramedullary nailing) under general anesthesia
4. Comminuted fractures

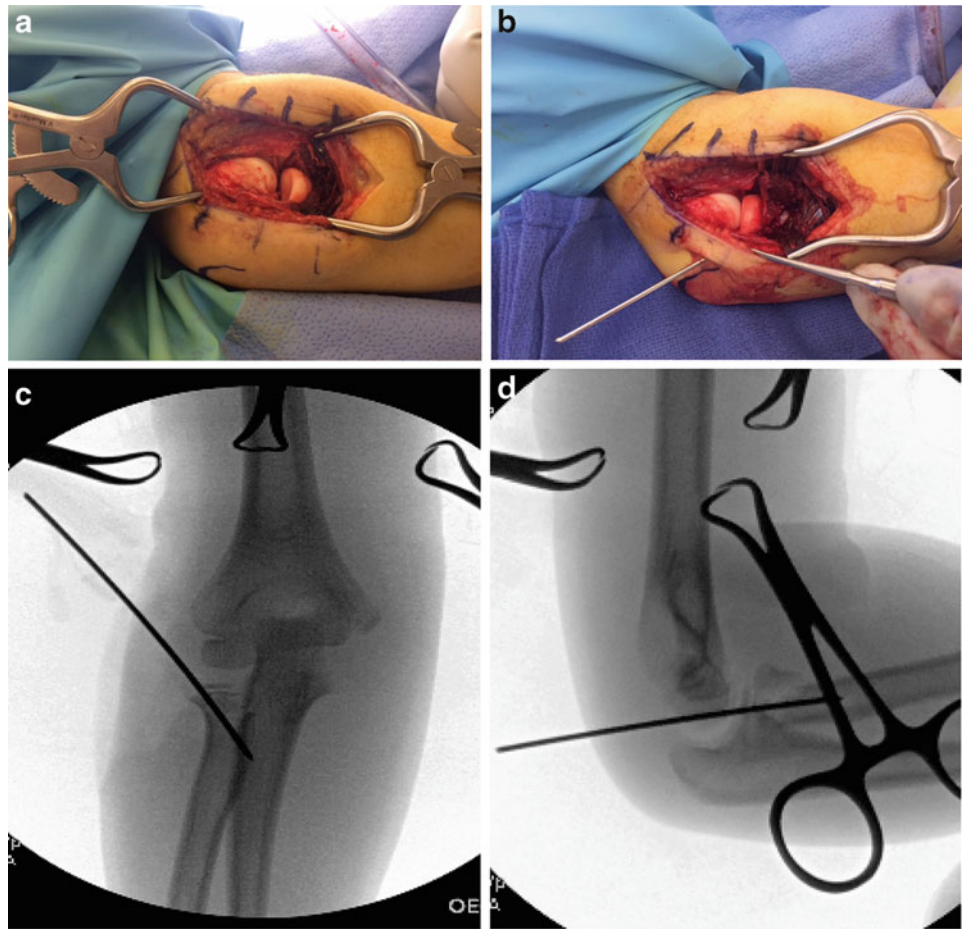
5. Associated fractures about the elbow requiring fixation
6. Associated compartment syndrome or neurovascular compromise

5 Basic Principles

The patient is placed supine on the operating table with a hand table attachment. Tourniquet is applied.

Open reduction is achieved through a lateral/Kocher approach. An oblique incision is made from lateral epicondyle to posterolateral aspect of the elbow (Fig. 2a). Alternatively a posterior approach just lateral to the olecranon may be utilized with elevation of a full thickness subcutaneous flap if there are associated fractures requiring fixation. The forearm is held in pronation to protect the posterior interosseous nerve, moving it more distally and medial. The interval between the anconeus and extensor carpi ulnaris is opened, splitting fibers in line with the muscle down to the capsule. The capsule is opened obliquely anterior to the lateral ulnar collateral ligament (LCL) exposing the radial head, shaft, and the annular ligament. The capsule and radial collateral ligament (RCL) may already be disrupted depending on the severity of the injury and this interval allows direct visualization of the fracture site. A reduction may now be performed under direct vision (Fig. 2b). Interposed muscle and capsule is removed to facilitate reduction. Reduction is assessed radiographically and clinically by the fit of the fragments. Once reduced the stability of the reduction is assessed. If the fracture is unstable following reduction, percutaneous fixation with 1–2 k-wires may be performed in the safe zone of the radial head (90° arc between Lister's tubercle and radial styloid). The k-wires are placed from the lateral aspect of the articular surface of the radial head across the fracture site to engage the medial cortex of the metaphysis of the radius (Fig. 2c, d). Alternatively, stabilization

Fig. 2 (a) Intraoperative clinical photo showing lateral approach through Kocher interval. Capitellum is seen with radial neck fracture in reduced position. (b) Percutaneous fixation with K-wire. (c, d) Intraoperative radiographs showing reduction and fixation



methods such as mini-fragment plates and headless compression screws may be used in patients close to skeletal maturity.

The capsule, muscular interval, and wound are closed in layers with absorbable suture. The k-wires are bent and cut and a well-padded long arm posterior splint is placed with the forearm in neutral rotation.

The pins are kept in place for 4–6 weeks until callus is noted at the fracture site. Range of motion is initiated only after pin removal. Supervised therapy is instituted if patient not progressing as expected (Fig. 5).

6 Images During Treatment

See Fig. 2a-d.

7 Technical Pearls

1. Limit periosteal stripping to reduce the risk of avascular necrosis (AVN) and nonunion.
2. Annular ligament may be cut to allow reduction but must be repaired.

3. Transcapitellar pins should be avoided as they may break in the joint.
4. Evaluate and repair radial collateral and lateral ulnar collateral ligament as needed.
5. Intramedullary nailing is an alternative technique that can be used for stabilization of the fracture after open reduction. This is done via either a dorsal or radial approach to the distal radius 1.5–2 cm proximal to the physis. The appropriately sized flexible titanium nail is passed under fluoroscopic guidance to the fracture site and is impacted into the epiphysis to maintain reduction. Care is taken not to breach the articular surface. The nail is then cut proud distally to facilitate later removal and skin closed with absorbable suture. The advantage of this is that it may be left in place until complete healing has occurred while avoiding the complications of percutaneous pins including need for early removal.

8 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

Fig. 3 (a, b) Lateral and AP views of the elbow at 6 weeks post op showing early bridging callus at which point k-wire is removed. The Fracture was assessed radiographically at 4 weeks postoperatively and no clear evidence of callus was seen, therefore pins were left in for an additional 2 weeks

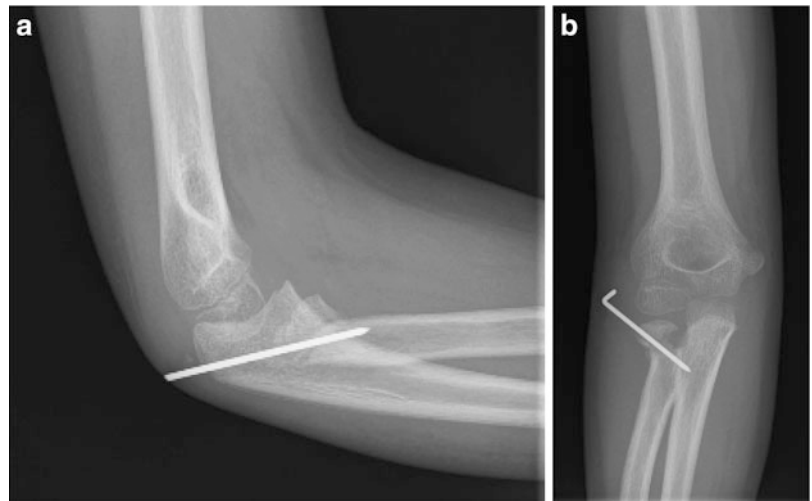


Fig. 4 (a, b, c) Lateral and oblique radiographs 8 weeks postoperatively demonstrating maintenance of alignment of fracture with bridging callus, but fracture is not yet fully united



Fig. 5 (a, b, c) AP lateral and oblique films at 4.5 months post op demonstrating interval healing of her radial neck fracture. At this point the patient is doing well and has been discharged from therapy. Her range of motion was 0–133° flexion and she had only mild limitation of terminal supination and pronation. No pain at this time



9 Avoiding and Managing Problems

1. Minimize attempts of percutaneous reduction prior to open reduction as iatrogenic injury to soft tissues may affect outcome.
2. High energy injuries are at risk for soft tissue disruption. Limiting further soft tissues injury and periosteal stripping

may reduce the risk of AVN and nonunion. This may also reduce the incidence of heterotopic ossification and radioulnar synostosis. Treatment of nonunion is non-operative if patient is asymptomatic and no significant functional limitation. Otherwise treatment options include radial head excision or ORIF with bone graft. Radial head excision should be reserved for skeletally mature patients.

3. Adequate fixation/stabilization is recommended in all operative cases. Recommend leaving in place until callus is present to prevent displacement of fracture and/or risk of nonunion.
4. Remove pins as soon as possible once callus is seen at fracture site. Leaving pins longer than 6 weeks increase the risk of pin site and intra-articular infection.
5. Initiate early protected motion once evidence of healing to reduce the risk of postoperative stiffness.
6. Premature physeal closure is rare but may cause deformity and loss of motion.

10 Cross-References

- [Radial Neck Fracture: Operative Treatment \(ESIN\) “Joy-Stick” Technique](#)

References and Suggested Reading

De Mattos CB, Ramski DE, Kushare IV, Angsanuntsukh C, Flynn JM (2016) Radial neck fractures in children and adolescents: an

examination of operative and nonoperative treatment and outcomes. *J Pediatr Orthop* 36(1):6–12

Falciglia F, Giordano M, Aulisa AG, Di Lazzaro A, Guzzanti V (2014) Radial neck fractures in children: results when open reduction is indicated. *J Pediatr Orthop* 34(8):756–762

Han Y, Hatch GF, Itamura JM (2016) Open reduction and internal fixation of radial head and neck fractures. In: Sankar WN, Flynn JM (eds) *Operative Techniques in Pediatric Orthopaedic Surgery*. Lippincott Williams & Wilkins, New York, pp 94–104

Pring ME (2012) Pediatric radial neck fractures: when and how to fix. *J Pediatr Orthop* 32(Suppl 1):S14–S21

Shabtai L, Arkader A (2016) Percutaneous reduction of displaced radial neck fractures achieves better results compared with fractures treated by open reduction. *J Pediatr Orthop* 36(Suppl 1):S63–S66

Zimmerman RM, Kalish LA, Hresko MT, Waters PM, Bae DS (2013) Surgical management of pediatric radial neck fractures. *J Bone Joint Surg Am* 95(20):1825–1832

Radial Neck Fractures: Operative Treatment, Special Conditions

Theddy Slongo

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Abstract

In childhood, the majority of fractures around the proximal radius are radial neck fractures, according the AO Pediatric classification (Slongo et al. J Pediatr Orthop 26:43–49, 2006, AO Pediatric comprehensive classification of long bone fractures (PCCF). AO Publishing, Davos, 2007) 21r – M and 21r – E fractures. With the introduction of the ESIN method, the indication for closed reduction and stabilization has been significantly expanded. For certain combinations of fracture pattern operative treatment is recommended. This article presents

two exemplary cases of radial neck fractures with the indication for surgical treatment.

1 Case 1: Displaced Radial Neck Fracture/Un-displaced Olecranon Fracture

1.1 Brief Clinical History

A 12-year-old boy sustained a sport injury on his left arm. The left elbow was severely swollen. Neurovascular situation normal.

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1.2 Preoperative Clinical Photos and Radiographs

Due to the clinical examination and the case history, an ap and lateral x-ray of the elbow was performed.

Figure 1 shows the ap and lateral x-rays of the elbow with a more than 45° angulated radial head which is additional translated nearly 50% of the shaft diameter (21r – M/3.1 II). On the other hand, an un-displaced olecranon fracture can be identified, which will be seen more clearly under image intensifier.

1.3 Preoperative Problem List

As no other skeletal injuries were diagnosed and the neuro-vascular situation was normal a surgery was planned, according to the algorithm of Type II and III fractures, but not as an emergency intervention.

This fracture is never an emergency surgery and the child profits from a good and experienced surgeon. Therefore, the operation can be scheduled in the normal operative day.

The olecranon fracture is un-displaced and normally this fracture needs only plaster cast immobilization.

1.4 Treatment Strategy

The degree of displacement of this fracture is a perfect indication to use the closed, indirect reduction, and intramedullary stabilization ESIN (Elastic Stable

Intramedullary Nailing) technique. It's important that a skilled surgeon who is performed this ESIN technique is present. On the other hand, as this fracture can be scheduled in the normal operative day, it allows to use this as a “teaching” operation, assisted by a ESIN-experienced surgeon.

In addition, the goal is a functional postoperative treatment. Therefore, the olecranon fracture needs also a stabilization. It is recommended, that the child should have the highest profit from the anesthesia and the operation. So, it should be discussed with the parents to stabilize both bones with a TEN. The less high risk of complication (only theoretical) of the additional operation can be tolerated. For the nail removal, the child has no disadvantages.

For this operation, an image intensifier is mandatory. In addition, the adequate instruments and implants (nails 2.0 mm or 2.5 mm) must be available (see Fig. 2).

2 Basic Principles in the Treatment

Table 1A shows a displaced radial neck fracture Type II or III which is an indication for indirect reduction with ESIN technique. This fracture is combined with an un-displaced olecranon fracture, which is in principle not an indication for operative treatment. In combination we recommend to stabilize both fractures with ESIN technique as the child should profit from the operation and be treated without cast.

Table 1B shows the different situation; a complete displaced olecranon fracture which is an indication for operative stabilization, on the other hand a Type I radial neck fracture, which is in principle not an indication for operative



Fig. 1 ap and lateral x-rays of the elbow with a more than 45° angulated radial head which is additional translated more than 50% of the shaft diameter (21 – E/3.1 II) diagnosed as a Salter-Harris II fracture

treatment. But in combination we follow the same rules as in Table 1A, the child should profit from the operation, so we stabilize both bones.

The basic principles of this treatment are the following:

1. Insertion of an elastic nail 2.0 mm or 2.5 mm, depending on the age/size of the child from the distal metaphysis of the radius

2. Advancement of the nail to the fracture line
3. Orientation of the nail tip towards the biggest angulation of the radial head and insertion of the nail tip in the head

4. A combination of external pressure to the radial head and internal reduction of the radial head by rotating the nail

5. Fixation of the reduced radial head

6. Free functional movement should be achieved

7. Plaster free mobilization of the forearm postoperative

8. Over a short dorsal incision preparation of the olecranon

9. Insertion of 2 1.6 mm K-wires for the wire tension band



Fig. 2 Position of the sterile draped forearm on the image intensifier

Table 1 (A) shows a combination of a displaced radial neck fracture (indication for operation) with an undisplaced olecranon fracture (which would not be a indication for operation). (B) shows the other situation

2.1 Images During Treatment

Positioning of the sterile draped forearm on the image intensifier (see Fig. 3).

Identification of the distal entry point. Today we recommend to use the Listers Tubercle approach or the traditional dorso-radial approach. Figure 4 shows the level of the skin incision, today along the skin line transverse. This level should be checked under intensifier.

The skin incision is then performed and a blunt dissection up to Lister’s Tubercle: attention should be paid to the retinaculum and the tendons as shown in Figs. 5 and 6.

Figure 7 shows the position of the awl, direct on the bone, a blind approach should be avoided. This entry point and the correct position of the awl must be checked under intensifier.

At the next step, the proximal third of the nail should be prebended (precontoured) as shown in the pictures. This facilitated the nail insertion and the indirect head reduction once the nail has reached the radial head (Fig. 8).

The well prebended nail is now inserted under visual control. Check the alignment of the nail tip under one image intensifier shot. In the next step, the nail is advanced under oscillating rotation up to the fracture; at this point it’s important to rotate under intensifier control in a way that the most severe angulation/displacement of the fracture can be seen. The prebended nail tip must be orientated to the displaced/angulated fracture.

with an undisplaced radial neck fracture with a displaced olecranon fracture. The more severe fracture is the leading fracture for operation indication

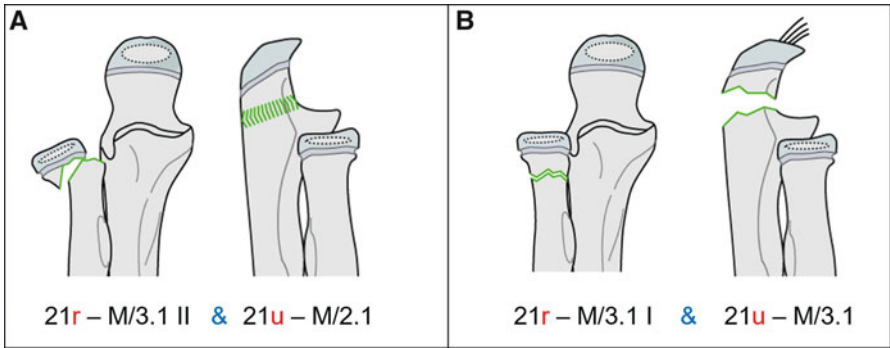




Fig. 3 Orientation/rotation of the proximal forearm for a correct visualization of the displacement/angulation of the radial neck fracture



Fig. 6 Blount dissection of the subcutaneous layers and the tendons

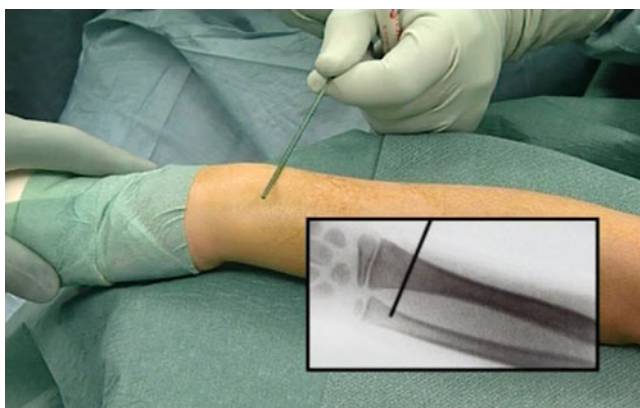


Fig. 4 Determination of the level of the entry point over the lister tubercle under intensifier control

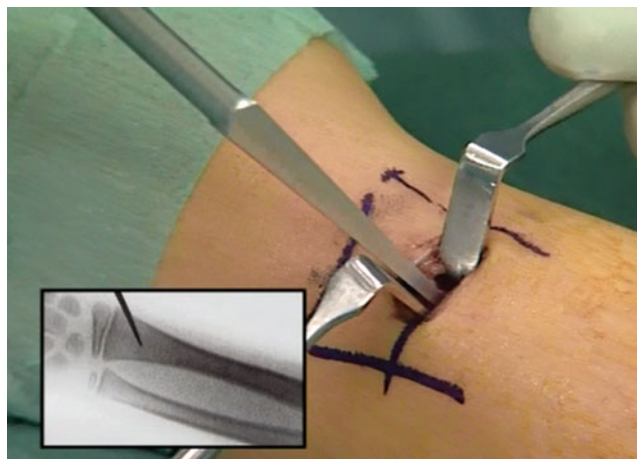


Fig. 7 Opening of the medullary canal with an awl under visual control

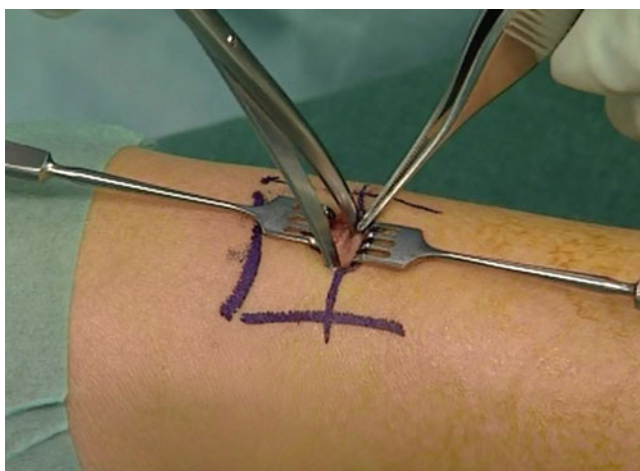


Fig. 5 3 cm long transverse skin incision along the skin lines



Fig. 8 Prebending of the first 5 cm of the nail for a better advancement and reduction of the femoral neck/head

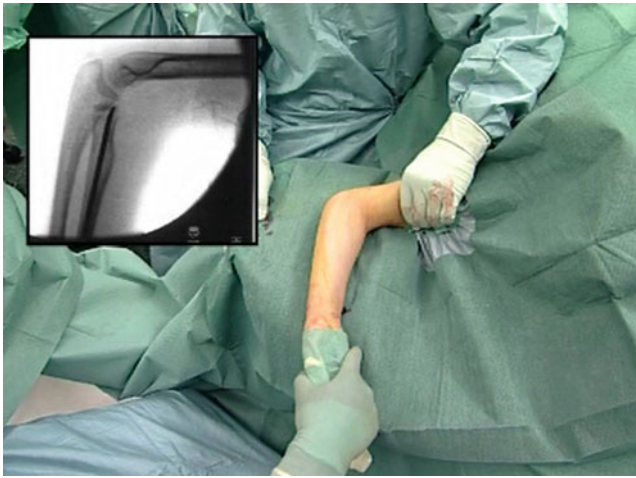


Fig. 9 Control of the reduction in lateral view



Fig. 10 Once the nail is in correct position and the fracture perfect reduced the nail is cut

Once the nail is correctly orientated, the nail is inserted into the radial head by gentle hammer blows. A single perforation for a better grip of the nail doesn't cause any growth disturbances.

Figure 2 shows a series of intraoperative steps and the perfect alignment of the reduced fracture.

Once the result is radiological perfect (and we should accept only perfect reduction with this technique), the nail is shortened (Fig. 9).

2.2 Technical Pearls

It's important to shorten the nail in the correct length:

Tips:

1. Use a bolt cutter which avoids sharp ends (Fig. 13)



Fig. 11 Under image intensifier the olecranon can be seen much better

2. Leave the nail-end over the retinaculum; under the retinaculum, there is a high risk for tendon irritation/rupture
3. Even a longer nail end does not irritate the extension of the hand (even you see a prominent buckle) and facilitates the nail removal (Fig. 10)

The slightly oblique view under image intensifier shows now the olecranon fracture much better (Fig. 11).

Once the olecranon is prepared and the fracture visualized, two 1.6 mm K-wires are inserted in the typical way for wire tension band. Figure 12 shows the intraoperative documentation with perfect adaptation of the olecranon.

2.2.1 Outcome Radiographs

An immobilization in an arm sling for 3–4 weeks is sufficient, depending on the age of the child. After 3 weeks, the first follow-up x-ray was made, showing a correct position and healing so that the child was allowed to return to sport (Fig. 13).

Figure 14 shows the full consolidation and perfect alignment after 3 months. Now the nail removal can be planned, depending on your local protocols. In our hand, we recommend to remove the nail.

No more controls were required; the child has asymmetrical range of motion and absolutely no restrictions.

2.3 Avoiding and Managing Problems

Depending on the child's activity and arm mobilization the unrestricted use of the forearm was allowed.

For such a fracture, long-term follow-up is not necessary. The parents are requested to return in 1 month if the arm is not normally used.

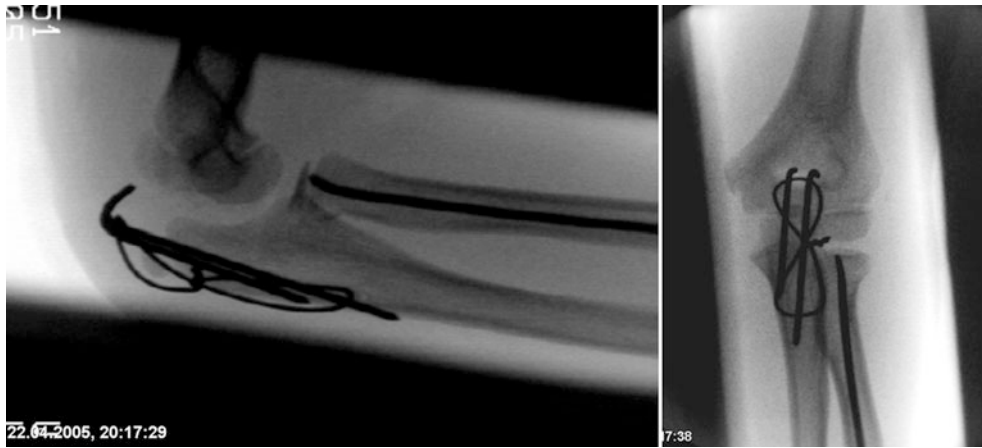


Fig. 12 Intraoperative documentation of the wire-tension band fixation of the olecranon fracture

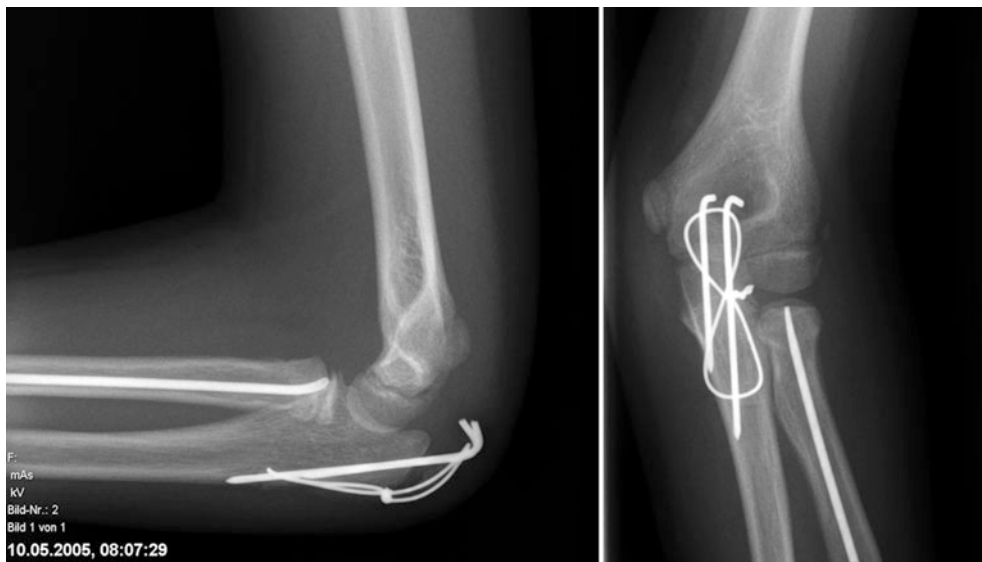


Fig. 13 Follow-up x-ray after 3 weeks, full range of motion is achieved, no pain. School sport is now allowed

3 Case 2: Un-displaced Radial Neck Fracture/Displaced Olecranon Fracture

3.1 Brief Clinical History

A 9-year-old girl had an accident during school gymnastics. The teacher reported that she fell from high. Neurovascular situation normal.

3.2 Preoperative Clinical Photos and Radiographs

Due the clinical examination and the case history, an ap and lateral x-ray of the elbow was performed.

Figure 15 shows the ap and lateral x-rays of the elbow with a minimal angulated radial head fracture (21r – M/3.1 I). On the other hand, we see a complete displaced olecranon fracture, with the olecranon fragment in the elbow joint (arrow).

3.3 Preoperative Problem List

In this situation, the radial neck fracture was not an indication for any kind of manipulation, only immobilization.

On the other hand, the complete displaced olecranon is a clear indication for open reduction and wire tension band fixation.

This situation was discussed with the parents and it was suggested to stabilize both fractures with the profit that the child does not need a plaster cast.

3.4 Treatment Strategy

The first step of this operation was the preparation of the olecranon fracture and classical stabilization with wire tension band technique.

In addition, the goal is a functional postoperative treatment. Therefore, the radial neck fracture was also stabilized with a TEN. The child should have a high benefit from the anesthesia and the operation. In this situation, a wire tension band requires always implant removal. Therefore, the

Fig. 14 3 months follow-up shows a full consolidation of both fractures with a perfect alignment. Normal range of motion. No more controls are planned

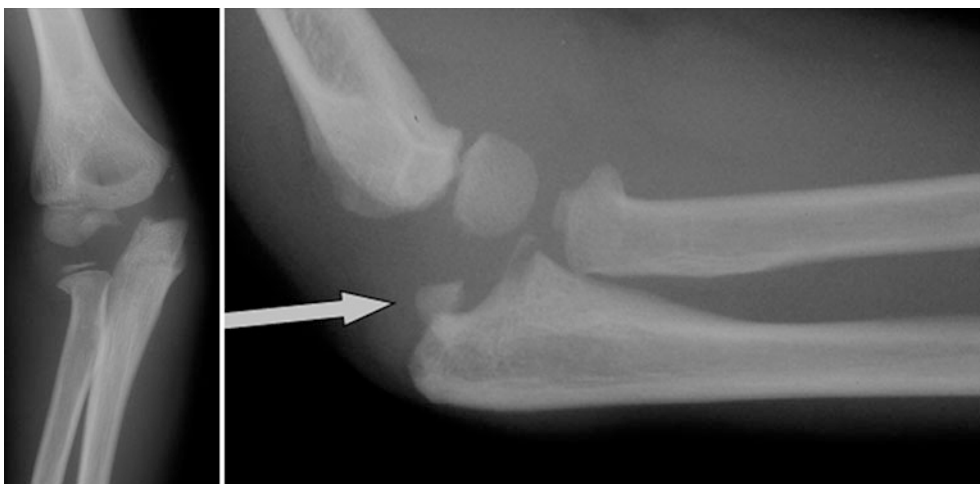


Fig. 15 Ap and lateral elbow x-ray of a 8-year-old girl with a fully displaced olecranon fracture and un-displaced radial neck fracture

additional removal of the nail is no disadvantages for the child or makes the operation longer.

For this operation, an image intensifier is mandatory. In addition, the adequate instruments and implants (nails 2.0 mm or 2.5 mm) must be available (see Fig. 2).

3.5 Basic Principles

The basic principles of this treatment are the following:

1. Stabilization of the olecranon in a typical wire tension band technique

4 Stabilization of the Radial Neck by Retrograde Elastic Nailing Technique

4.1 Images During Treatment

We start normally with the radial neck fracture and for this treatment, as it is a closed treatment, (we try to avoid opening the joint during the treatment of the olecranon fracture) we need the image intensifier. These are the only radiological pictures we need.

Alternatively, if you would avoid using intensifier, you start with the open reduction and fixation of the olecranon fracture. By an extension of the capsule opening on the radial side, we see the displaced radial head and with a dentist hook we can pull carefully on the radial head, at the same time the pre-placed elastic nail pushes the head under visual control in

an anatomical position. But anyway, we recommend to use intensifier.

4.1.1 Technical Pearls

The biggest advantage of this procedure is a functional post-operative treatment. This has a high influence on the functional outcome regarding pro- and supination. In all other procedures, we need a plaster cast immobilization and this can result in a limited pro- and supination.

4.1.2 Outcome Radiographs

An immobilization in an arm sling for 3–4 weeks is sufficient, depending on the age of the child. After 4 weeks, the first follow-up x-ray was made, showing a correct position and healing so that the child was allowed to return to sport (Fig. 16).

Figure 17 shows the full consolidation and perfect alignment after 3 months. Now the nail and the wires tension band removal can be planned, depending on your local protocols. In our hand, we recommend to remove the nail.

No more controls were required; the child has asymmetrical range of motion and absolutely no restrictions.

4.2 Avoiding and Managing Problems

Depending on the child's activity and arm mobilization, the unrestricted use of the forearm was allowed.

In our hand, for such an unproblematic fracture, no long-term follow-up is planned. The parents are requested for a visit if in 1 month the arm cannot be used normally.



Fig. 16 First follow-up x-ray after 4 weeks with good alignment; school sport is now allowed



Fig. 17 Last follow-up x-ray after 3 months. Full consolidation, normal alignment and function. No more controls are required

5 Cross-References

► Radial Neck Fractures: Operative Treatment (ESIN)

References and Suggested Reading

- Basmajian HG, Choi PD, Huh K, Sankar WN, Wells L, Arkader A (2014) A radial neck fractures in children: experience from two level-1 trauma centers. *J Pediatr Orthop B* 23(4):369–374
- Dietz HG, Schmittenbecher PP, Slongo TF, Wilkins KE (2006) AO manual of fracture management. Elastic stable intramedullary nailing (ESIN) in children. Thieme, Stuttgart
- Falciglia F, Giordano M, Aulisa AG, Di Lazzaro A, Guzzanti V (2014) Radial neck fractures in children: results when open reduction is indicated. *J Pediatr Orthop* 34(8):756–762
- Gonzalez-Herranz P, Alvarez-Romera A, Burgos J, Rapariz JM, Hevia E (1997) Displaced radial neck fractures in children treated by closed intramedullary pinning (Metaizeau technique). *J Pediatr Orthop* 17:325–331
- Klitscher D, Richter S, Bodenschatz K et al (2009) Evaluation of severely displaced radial neck fractures in children treated with elastic stable intramedullary nailing. *J Pediatr Orthop* 29:698–703
- Lascombe P (2006) Embrochage centromédullaire élastique stable. Elsevier Masson, Issy-les Moulineaux
- Metaizeau JP, Lascombes P, Lemelle JL, Finlayson D, Prevot J (1993) Reduction and fixation of displaced radial neck fractures by closed intramedullary pinning. *J Pediatr Orthop* 13:355–360
- Schmittenebecher PP, Haevernick B, Herold A, Knorr P, Schmid E (2005a) Treatment decision, method of osteosynthesis, and outcome in radial neck fractures in children. *J Pediatr Orthop* 25:45–50
- Schmittenebecher PP, Haevernick B, Herold A, Knorr P, Schmid E (2005b) Treatment decision, method of osteosynthesis, and outcome in radial neck fractures in children: a multicenter study. *J Pediatr Orthop* 25:45–50
- Slongo T, Audigé L, Schlickewei W, Clavert JM, Hunter J (2006) Development and validation of the AO pediatric comprehensive classification of long bone fractures by the pediatric expert group of the AO foundation in collaboration with AO clinical investigation and documentation and the international association for pediatric traumatology. *J Pediatr Orthop* 26:43–49
- Slongo T, Audigé L, AO Classification Group (2007) AO Pediatric comprehensive classification of long bone fractures (PCCF). AO Publishing, Davos
- Vocke AK, von Laer L (1998) Displaced fractures of the radial neck in children: long-term results and prognosis of conservative treatment. *J Pediatr Orthop Part B* 1(7):217–222

Proximal Third Both Bone Forearm Fractures

David B. Johnson and Christopher A. Iobst

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Abstract

Both bone forearm fractures (BBFF) are among the most common fractures seen in the pediatric population, accounting for 5–10% of all pediatric fractures. Anatomically, these injuries are subdivided into distal, middle, and proximal thirds, with distal injuries being most common. The bony architecture of the radius changes from proximal to distal, going from cylindrical, transitioning through triangular to elliptical as it approaches the distal portion of the forearm. This, in part, is why distal injuries are more common. Additionally, the muscular envelope in the proximal forearm helps prevent fractures in this region. Tendinous attachments of the proximal forearm

also lead to a reproducible displacement pattern, with the proximal fragment being flexed and externally rotated due to the unopposed pull of the supinator and biceps muscles. The majority of BBFF can be treated with closed reduction and casting, with the forearm placed in a neutral to supinated position for proximal third fractures. However, the remodeling potential following proximal third injuries is significantly decreased given its distance from the more active, distal radius physis. Thus, patients with proximal BBFF have a more guarded prognosis and more stringent reduction parameters. If adequate closed reduction cannot be maintained, operative stabilization is required to prevent residual functional deficits. Commonly used surgical options include intramedullary nailing and open reduction internal fixation (ORIF).

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1 Brief Clinical History

The patient is a 10-year-old male who presented to the emergency department for evaluation after a fall from a trampoline. He reports isolated pain about the right forearm. Evaluation of the right arm demonstrates an obvious deformity about the

Fig. 1 (a–b) Radiographs at presentation demonstrating a closed, proximal one third, same level, both bone forearm fracture



proximal forearm. Ecchymosis was noted volarly, but no open wounds were identified. He was neurovascularly intact to the right upper extremity. Radiographs of the forearm and humerus were obtained, which demonstrated a proximal one third, same level, BBFF. Several attempts at closed reduction were made in the emergency department with the aid of the mini C-arm but were unsuccessful. At that time, the patient was placed in a well-padded long arm posterior splint. The patient was admitted to the hospital for closed vs open reduction of his right BBFF as well as overnight monitoring for compartment syndrome.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1a, b.

3 Preoperative Problem List

1. Right, closed, proximal third both bone forearm fracture.
2. Monitoring for compartment syndrome.

4 Treatment Strategy

Closed reduction of proximal third BBFF is a difficult task. Closed reduction is first attempted in the emergency department under conscious sedation by providing in-line traction with gentle pronation or supination. Generally, with proximal third BBFF, the proximal fragment is supinated, given the unopposed pull of the supinator and biceps brachii. Thus, the reduction maneuver typically involves traction and supination of the distal fragment. If adequate reduction is obtained, a well-molded long arm cast, consisting of a three-point mold and straight ulnar border, is applied. Inconsistencies exist in the literature regarding the parameters of “adequate”

reductions for proximal BBFF. However, in general, less than 10° of angulation, no malrotation, and no bayonet apposition are cited for proximal third fractures (Vopat et al. 2014). Patients should be followed weekly, with radiographs, for the first several weeks to confirm maintenance of reduction, as these fractures have a high propensity for displacement.

If closed reduction is unattainable in the emergency department, the patient should be placed in a well-padded long arm posterior splint and admitted for attempted closed reduction under general anesthesia vs operative stabilization (ORIF, intramedullary stabilization). Additionally, the patient should be monitored overnight for compartment syndrome following unsuccessful closed reduction. Intraoperatively, closed reduction under general anesthesia is first attempted. If still unsuccessful, operative stabilization is performed. Two main treatment options exist: ORIF and intramedullary fixation.

With ORIF, two incisions are typically used to lessen the risk of synostosis. Approaches to the proximal radius are twofold. Volarly, the Henry approach can be utilized between the brachioradialis and flexor carpi radialis distally and the brachioradialis and pronator teres proximally. Additionally, a dorsal approach described by Thompson can also be used between the extensor carpi radialis brevis and extensor digitorum. To approach the ulna, a subcutaneous approach, creating a plane between the extensor carpi ulnaris and flexor carpi ulnaris, is utilized. Fixation of at least four cortices proximal and distal to the fracture site should be obtained.

Conversely, intramedullary stabilization may be used, as was done in this case example. Typically, the ulna is approached first, as this sometimes aids in reduction of the radius. The ulnar intramedullary device, either a flexible nail or straight Steinmann pin, is inserted in an antegrade fashion from a starting point centered on the olecranon apophysis or through the anconeus posterolaterally. Additionally, a small incision can be made over the fracture site to aid in reduction of the fracture and passage of the intramedullary implant if needed. Once the

ulna is stabilized, the forearm is again manipulated. If the radius is able to be anatomically close reduced and felt to be stable, then the procedure is complete, and the patient can be splinted and later transitioned to a cast. If the radius fracture is unstable or malreduced, a retrograde radial intramedullary nail is inserted through a metaphyseal starting point between the first and second and second and third dorsal compartments of the wrist. Prior to insertion, the radial nail should be bent approximately 15–20° to match the radial bow and allow for three points of fixation against the cortex.

If operative stabilization of the radius and ulna is utilized, patients are placed in a long arm posterior splint postoperatively for 2–3 weeks until wound healing is complete. Early mobilization after this time can be considered if the fracture was stable intraoperatively, and good three-point fixation was obtained. If single bone fixation is performed, the patient is placed in a splint and later transitioned to a cast once surgical wounds are healed.

5 Basic Principles

1. Closed reduction and casting are the first line of treatment for proximal third BBFF.
2. Adequate closed reduction is difficult to obtain for these fractures; <10° angulation, no malrotation, and no bayonet apposition are acceptable.

3. Fractures that are more proximal, in patients ≥ 10 years old, and with apex ulnar angulation are more likely to fail with closed treatment (Bowman et al. 2011).
4. ORIF and intramedullary fixation are the two commonly used procedures for operative stabilization of proximal third BBFF.
5. Even with intramedullary nailing, open reduction is often needed. A small incision can be made directly over the fracture site to facilitate reduction.
6. Union rates are similar between ORIF and intramedullary fixation groups for BBFF, 98.3 and 97.6%, respectively. However, delayed union is more common in older patients (>10 years old) treated with intramedullary fixation (Baldwin et al. 2014).
7. Major complications defined as nonunion, compartment syndrome, infection, refracture, nerve injury, and unexpected return to the operating room are similar between both procedures (Baldwin et al. 2014).
8. Early mobilization can begin after operative stabilization is performed if stable reduction and adequate fixation are obtained.

6 Images During Treatment

See (Fig. 2a-d).

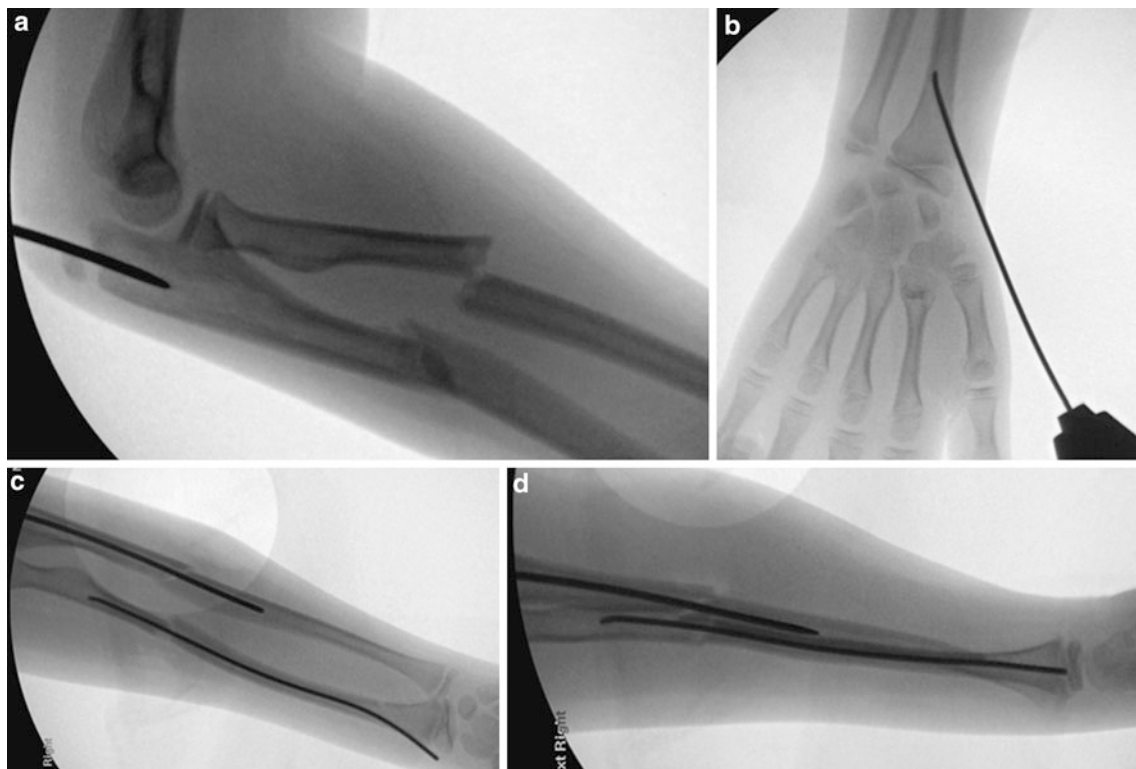


Fig. 2 Proximal ulnar starting point through the olecranon apophysis (a). Distal radius metaphyseal starting point (b). Anteroposterior (c) and lateral (d) fluoroscopic images of the reduced fracture with intramedullary fixation

7 Technical Pearls

1. Traction of the distal forearm with supination is the typical reduction maneuver. The proximal fragment is in a supinated position secondary to the unopposed force of the biceps brachii and supinator muscles.
2. Casting of the elbow in more extension can lessen the supination force on the proximal fragment. Additionally, this will allow for a better three-point mold at the fracture site.
3. Marking the location of the fracture on the cast, either with a pen or metal bead, prior to molding can help create a more accurate three-point mold. Often times, the fracture is more proximal in the cast than anticipated.
4. Rotation can be difficult to judge, especially in proximal fractures where the majority of deforming forces are rotational. Double check rotation with radiographic parameters following reduction. The bicipital tuberosity and radial styloid should be oriented 180° from each other, as should the coronoid and ulnar styloid on a true anteroposterior radiograph.
5. If intramedullary nailing is performed, using a straight implant (Steinmann pin or straight elastic nail) is helpful for reduction and passage when reducing the ulna. Conversely, pre-bending an elastic nail (15–20°) prior to insertion of the radius helps with passage, restoring the radial bow and obtaining three points of fixation in the radius. Maximum bend should be placed at the fracture site.
6. Making the incision more distal for retrograde flexible nails and more proximal for antegrade nails helps prevent skin traction. Additionally, over-drilling the insertion through the cortex helps with implant passage.
7. Creating an entry hole for the distal radius nail can be performed with the awl instead of the drill. This helps

prevent inadvertent damage to the surrounding tendons by the drill.

8. Have a low threshold for open reduction, even with nailing, as this is commonly needed to assist in reduction and passage of the nail.
9. Nail diameter is depending on canal diameter, with a goal of having a nail that is approximately 40% of the canal diameter (Lascombes et al. 2006).
10. Approach the ulna first, occasionally, following ulnar fixation a stable anatomic reduction of the radius can be performed without an open procedure (Flynn and Waters 1996).

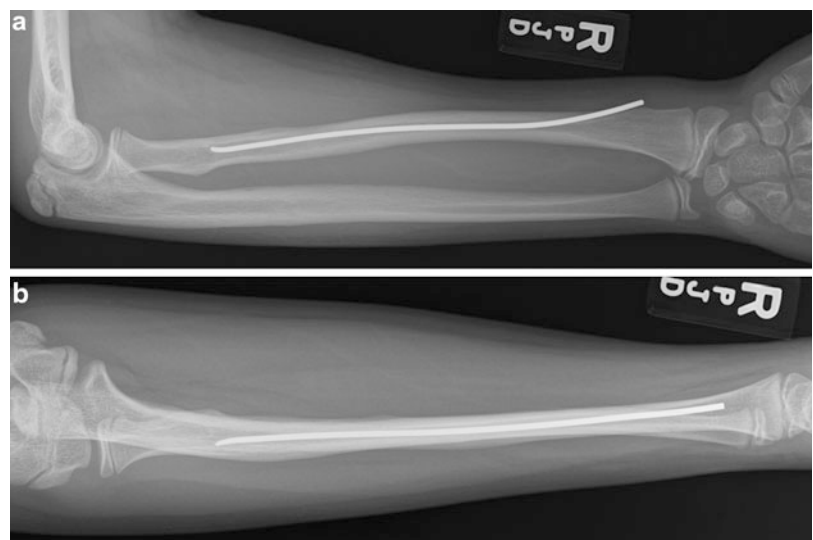
8 Outcome Clinical Photos and Radiographs

See (Fig. 3a, b).

9 Avoiding and Managing Problems

1. Patients being managed with closed reduction and casting should get weekly radiographs for the first 2–3 weeks to insure maintenance of reduction. This allows for early recognition of loss of reduction and time for cast wedging or re-manipulation to be performed.
2. Compartment syndrome can develop following intramedullary fixation of BBFF. To avoid this risk, limit unsuccessful passes of the nail to three attempts. After three attempts, perform an open reduction to aid in passage of the nail. Additionally, the tourniquet should not be inflated during nail passage, as this has been associated with development of compartment syndrome (Vopat et al. 2014; Yuan et al. 2004).

Fig. 3 Anteroposterior (a) and lateral (b) radiographs of the healed proximal third BBFF with maintenance of the radial intramedullary device



3. Synostosis can occur following ORIF of BBFF; this risk is mitigated with the use of two incisions.
4. Malrotation can be subtle, especially when reducing proximal third fractures. Obtain adequate AP and lateral radiographs of the proximal radius and ulna as well as distally at the wrist. This will allow you to double check the rotation using the 180-degree relationship of the bicipital tuberosity and radial styloid. Similarly, the coronoid and ulnar styloid should also be oriented 180° from each other.

References and Suggested Reading

- Baldwin K, Morrison MJ, Tomlinson LA, Ramirez R, Flynn JM (2014) Both bone forearm fractures in children and adolescents, which fixation strategy is superior—plates or nails? A systematic review and meta-analysis of observational studies. *J Orthop Trauma* 28(1): e8–e14
- Bowman EN, Mehlman CT, Lindsell CJ, Tamai J (2011) Non-operative treatment of both-bone forearm shaft fractures in children: predictors of early radiographic failure. *J Pediatr Orthop* 31(1):23–32
- Flynn JM, Waters PM (1996) Single bone fixation of both-bone forearm fractures. *J Pediatr Orthop* 16(5):655–659
- Lascombes P, Haumont T, Journeau P (2006) Use and abuse of flexible intramedullary nailing in children and adolescents. *J Pediatr Orthop* 26:827–834
- Vopat ML, Kane PM, Christino MA, Truntzer J, McClure P, Katarincic J, Vopat BG (2014) Treatment of diaphyseal forearm fractures in children. *Orthop Rev* 6(2):5325
- Yuan PS, Pring ME, Gaynor TP, Mubarak SJ, Newton PO (2004) Compartment syndrome following intramedullary fixation of pediatric forearm fractures. *J Pediatr Orthop* 24:370–375

Part II

Upper Extremity: Forearm, Wrist, and Hand

Midshaft Both Bone Forearm Fracture: Plate Fixation

Andrea Bauer

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Abstract

Forearm fractures are among the most common pediatric fractures. The location of the fracture and the age and skeletal maturity of the patient determine how much deformity can be tolerated and therefore which treatment methods are best. For adolescent patients with displaced both-bone forearm fractures, open reduction and plate fixation enable an anatomic reduction. In general, a volar approach to the radius and a subcutaneous approach to the ulna are used. Appropriately sized plates can range from 1.5 to 3.5 mm depending on the age and size of the patient.

1 Brief Clinical History

A 13-year-old left-hand dominant girl fell off the balance beam in gymnastics practice, landing on her outstretched left arm. She had immediate pain and visible deformity in the left forearm. She was taken by ambulance to a local hospital, where x-rays demonstrated displaced mid-shaft radius and ulna fractures. She underwent closed reduction under conscious sedation and was placed into a long arm cast. Figures 1 and 2 demonstrate the postreduction radiographs. As can be seen in the figures, after this attempted reduction, there was still bayonet apposition of the ulna and both rotational and angular deformity of the radius. As this patient is nearing skeletal maturity, the decision was made to proceed with open reduction internal fixation of both fractures to provide full correction of the residual deformity.

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2 Preoperative Clinical Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Mid-shaft radius and ulna fractures with residual deformity after closed reduction
 - (a) Bayonet apposition of the ulna
 - (b) Rotational deformity of the radius
2. Patient near skeletal maturity
3. Choice of surgical approach
4. Choice of fracture fixation



Fig. 1 Postreduction AP radiograph of the forearm. Notice that the bicipital tuberosity cannot be seen opposite the radial styloid, suggesting significant rotational deformity in the radius

4 Treatment Strategy

Emergency department management consisted of closed reduction and casting. Generally, the cast should be a long-arm bivalved cast for this type of fracture. For the mid-shaft radius and ulna in a child over the age of 8 years, only up to 10 degrees of angulation is accepted; no rotation is accepted. This is in contrast to younger children, in whom we can accept up to 20 degrees of angulation and bayonet apposition. For this fracture, acceptable alignment could not be achieved through closed reduction. Treatment options included intramedullary nail fixation versus open reduction internal fixation with plates. In this older child with a rotational deformity, open reduction and internal plate fixation of both bones were chosen to achieve and maintain an anatomic reduction. The dorsal Thompson approach to the radius was chosen for this fracture because of its relatively proximal location. A volar Henry approach could also have been used. The subcutaneous approach was used for the ulna. Fracture reduction was performed using reduction clamps and held provisionally with a K-wire in the radius (Fig. 3). Different sizes of hardware may be needed depending on the age of the child; in this case, stacked one-third tubular 3.5 mm plates were used in standard compression fashion (Figs. 4 and 5). At the conclusion of the surgery, forearm rotation was evaluated and was complete. The patient was immobilized in a bivalved long arm cast for 4 weeks, followed by a short arm cast for 2 weeks, before allowing a gradual return to full activity.

5 Basic Principles

1. Anatomic reduction of the radius and ulna is required in children nearing skeletal maturity in order to allow full forearm rotation.
2. Hardware size will vary based on the age and size of the child.
3. When postoperative immobilization is planned, as is usually the case in the pediatric forearm, we can accept four cortices of fixation above and below the fracture site instead of six.

6 Images During Treatment

See Figs. 3, 4, 5, and 6.

7 Technical Pearls

1. Rotational deformity will not remodel. It is necessary to carefully evaluate postreduction radiographs to determine whether the rotational alignment is acceptable. Rotational



Fig. 2 Postreduction lateral radiograph of the forearm. Notice that the widths of the cortices at the radius fracture site are different, again suggesting rotational deformity in the radius. The bayonet apposition of the ulna fracture site can be seen in this view as well



Fig. 3 Provisional fixation of the radius is achieved with a pointed reduction clamp and held with a K-wire

alignment is correct if the radial styloid is opposite the bicipital tuberosity and the coronoid is opposite the ulnar styloid on the AP forearm radiograph. On both the AP and lateral radiographs, the widths of the cortices just proximal and distal to the fracture sites will be different if there is substantial rotational deformity.

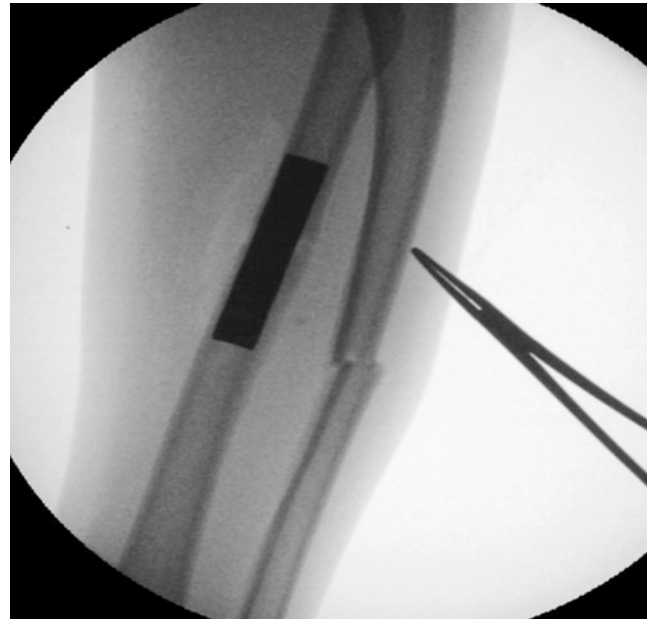


Fig. 4 After definitive fixation of the radius, the incision site for the ulna is localized under fluoroscopy



Fig. 5 Final intraoperative AP fluoroscopic image. Notice that there are only two screws placed in the ulna distal to the fracture site

2. When pediatric forearm fractures cannot be reduced anatomically, there is often periosteum or muscle interposed in the fracture site. The fracture site should be debrided of any interposed material before attempting open reduction.
3. Open reduction is performed with one or two pointed reduction clamps. Provisional fixation with a K-wire positioned out of the way of the planned plate position is very



Fig. 6 Final intraoperative lateral fluoroscopic image. Notice that there are only two screws proximal and two screws distal to the radius fracture site



Fig. 8 Final lateral radiograph 8 weeks after surgery. Again bony union can be seen



Fig. 7 Final AP radiograph 8 weeks after surgery. Bony union can be seen at both the radius and ulna fracture sites

helpful to maintain control of the fracture during definitive plate fixation.

4. The size of the plates used will vary based on the age and size of the child. The size of the hardware needed can be anticipated by measuring preoperative radiographs, but it is also useful to have a few options available in the operating room.

5. Prophylactic fasciotomies can be completed at the time of open reduction. Unlike in the lower extremity, muscle herniation through fasciotomy sites is not typically an issue in the forearm, so this can be done without added risk to the patient. Fasciotomy is completed through the site of the open reduction, using long tenotomy scissors. Placement of an army-navy or other large retractor at the apex of the wound allows the fasciotomy to be done under direct visualization.
6. Surgical wounds in children should be closed with absorbable sutures whenever possible to minimize the discomfort of suture removal in the postoperative period.

8 Outcome Radiographs

See Figs. 7 and 8.

9 Avoiding and Managing Problems

1. Use the approach to the radius that you are most comfortable with. Successful reduction and fixation can be achieved via both dorsal and volar approaches.
2. Cast immobilization postoperatively until bony union is a “belt and suspenders” approach to minimize risk of fracture displacement in the early postoperative period. This is appropriate because the daily activity level of children is much higher than adults and the risk of stiffness from immobilization is much lower.

3. Pain more than 2–3 days after surgery is not typical, and in general, postoperative pain should be easily managed with oral medication. Excessive pain in the postoperative period should be taken seriously, as this may be a sign of compartment syndrome, nerve injury, fracture displacement, or infection.
4. Pediatric forearm fractures have a 5% rate of refracture at the same site within the first year. If plate and screw removal is desired by the family, this should be delayed until 1 year after the initial surgery if possible.

References and Suggested Readings

- Baldwin K, Morrison MJ 3rd, Tomlinson LA, Ramirez R, Flynn JM (2014) Both bone forearm fractures in children and adolescents, which fixation strategy is superior – plates or nails? A systematic review and meta-analysis of observational studies. *J Orthop Trauma* 28(1):e8–e14
- Franklin CC, Robinson J, Noonan K, Flynn JM (2012) Evidence-based medicine: management of pediatric forearm fractures. *J Pediatr Orthop* 32(Suppl 2):S131–S134
- Vopat BG, Kane PM, Fitzgibbons PG, Got CJ, Katarincic JA (2014) Complications associated with retained implants after plate fixation of the pediatric forearm. *J Orthop Trauma* 28(6):360–364

10 Cross-References

- [Midshaft Both Bone Forearm Fracture: Intramedullary Rod Fixation](#)
- [Midshaft Both Bone Forearm Fracture: Single Bone Fixation](#)

Midshaft Both Bone Forearm Fracture: Intramedullary Rod Fixation

Felicity G. L. Fishman

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Abstract

A 10-year-old right-hand dominant male sustained closed diaphyseal fractures of his radius and ulna. He underwent attempted closed reduction and casting of his fractures in the Emergency Department under conscious sedation. The fracture pattern was found to be unstable and therefore he underwent open reduction and intramedullary fixation of his radius and ulna in the operating room. Intramedullary fixation can be performed with small incisions and minimal soft tissue disruption, even when open reduction is required. Based on his age and fracture pattern, his fractures were felt to be appropriate for intramedullary fixation. The radius fracture required open reduction in order to achieve acceptable alignment as periosteum remained interposed at the fracture site. Both the radius and ulna were stabilized with elastic nails. After stabilization,

patients require a period of cast immobilization. Most patients elect to have hardware removal after the fracture is united. This patient achieved union of his radius and ulna fractures with uneventful hardware removal at approximately 6 months after his initial surgery.

1 Brief Clinical History

A 10-year-old right-hand dominant male slipped at his home sustaining an injury to his right forearm. He was evaluated in the emergency department and radiographs demonstrated displaced diaphyseal radius and ulna fractures. He underwent attempted closed reduction of his fractures but the fracture pattern was found to be unstable and acceptable alignment could not be maintained in a cast. The patient was brought to the operating room 3 days after his initial injury at which time a closed reduction with full muscle relaxation was not possible. Therefore, open reduction and intramedullary fixation of both the radius and ulna were performed.

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Fig. 1 AP (a) and lateral (b) view of right radius and ulna at the time of presentation to the Emergency Department

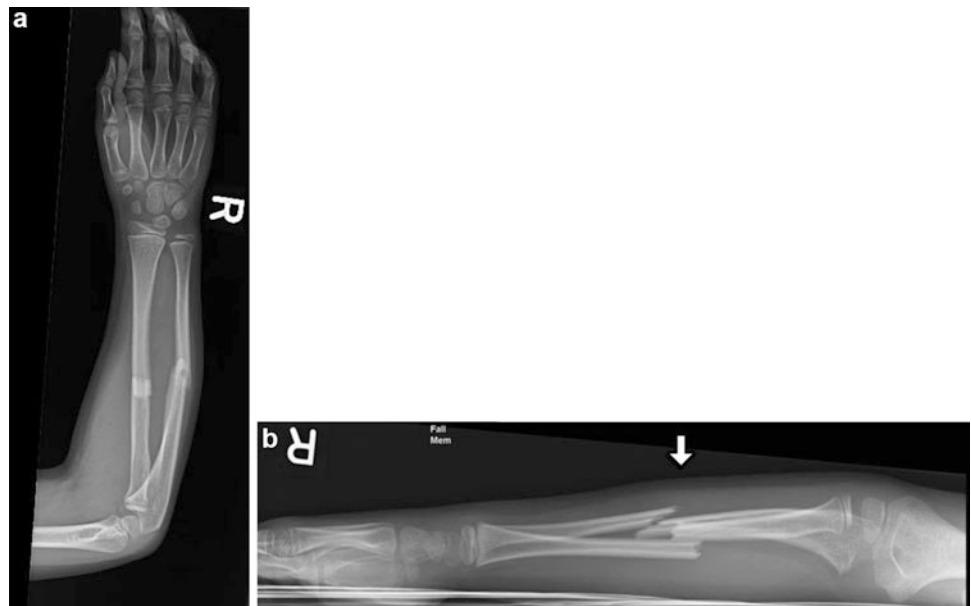


Fig. 2 AP (a) and lateral (b) view of right radius and ulna fractures after attempted closed reduction under conscious sedation in the Emergency Department

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Midshaft transverse radius fracture
2. Midshaft short oblique ulna fracture
3. Fractures at the same level of both bones (mid-diaphyseal) increasing instability
4. Physically immature patient

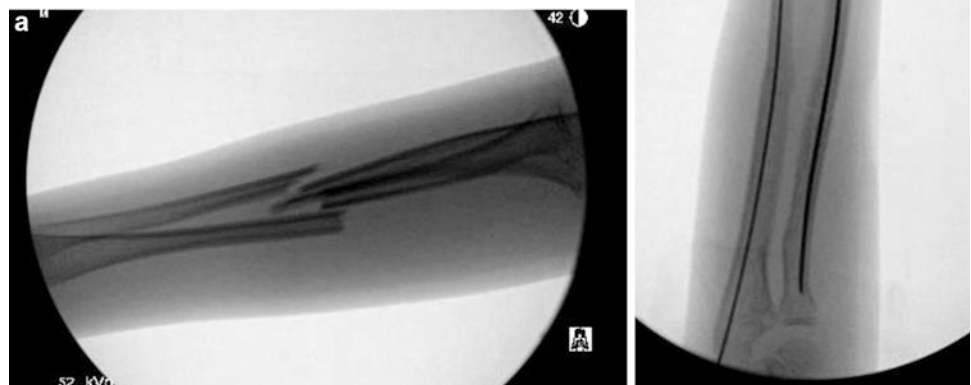
4 Treatment Strategy

Closed reduction was attempted in the emergency department. The fracture pattern, a short oblique ulnar mid-diaphyseal fracture and transverse mid-diaphyseal radius fracture, was inherently unstable in a long arm cast. Although there is no consensus regarding absolute indications for surgery, many surgeons will consider surgical reduction and stabilization for $\geq 10^\circ$ of angulation in the proximal forearm, $\geq 15^\circ$ of angulation for mid-shaft forearm fractures, and $\geq 30^\circ$ of malrotation in a male ≥ 10 years old with greater than 2 years growth remaining. This patient's fracture pattern could be potentially stabilized with open reduction and plate fixation or intramedullary fixation. Plate fixation requires considerable soft tissue dissection in comparison to intramedullary fixation; therefore intramedullary nails were felt to be the best surgical option. The patient was positioned supine with the affected arm extended onto a hand Table. A nonsterile tourniquet was placed around the upper arm, but not elevated during the procedure, to attempt to minimize swelling and potential reperfusion injury. After full muscle paralysis, a closed

reduction could not be achieved. A small incision was made directly over the radius fracture site and an anatomic reduction was achieved after interposed periosteum was extracted. The ulna was easily reduced in a closed fashion after the radial length was restored. The ulna is typically stabilized first, as the intramedullary nail placement is generally more straightforward. However, the radial reduction was relatively unstable and therefore the radius fixation was accomplished first in this particular case. After prebending the nail, the radial nail was placed from distal to proximal with an entry point proximal to the distal radial physis along the radial border of the radius. The ulnar nail was passed through the olecranon apophysis from proximal to distal. If the ulna is approached first and stabilized with an elastic nail, consideration can be given to unibone fixation. The radius reduction should be critically addressed under fluoroscopy for stability and maintenance of alignment before the surgeon should decide not to stabilize the radius fracture with internal fixation.

Postoperatively, the patient was placed in a long arm cast for 2 weeks, followed by a short arm cast for an additional 4 weeks. If unibone fixation is undertaken, a long arm cast is necessary postoperatively. If both forearm bones are stabilized with elastic nails, consideration can be given to using a short arm cast immediately after surgery. The patient was allowed to return to full activity at 3 months following his injury, while wearing a fracture brace. As the hardware can be prominent at the insertion points of the distal radius and proximal ulna, it is typically removed at 6 months to 1 year postoperatively.

Fig. 3 Intraoperative fluoroscopic views before (a) and after (b) open reduction and intramedullary fixation of radius and ulna diaphyseal fractures



5 Basic Principles

1. Intramedullary fixation can be utilized for midshaft both bone forearm fractures if a reduction cannot be maintained with a cast alone.
2. Intramedullary fixation has been associated with shorter operative times and better cosmetic outcomes than open reduction and internal fixation with plates and screws.
3. If the reduction cannot be obtained in a closed fashion, a small incision can be made over the fracture site in order to perform an open reduction. Periosteum and/or muscle may be interposed, blocking reduction.
4. Closed fractures that require an open reduction are associated with a higher rate of nonunion than those treated with IM fixation with closed reduction. Multiple attempts at passing a nail have been associated with a higher rate of compartment syndrome. A general rule of thumb is to perform an open reduction if the fracture cannot be reduced in ≤ 3 attempts.

6 Images During Treatment

See Fig. 3.

7 Technical Pearls

1. Prebend intramedullary wires to attempt to restore radial bow. The nail can be bent to mimic the natural radial bow (a lazy z-shape with a short limb distally and longer C

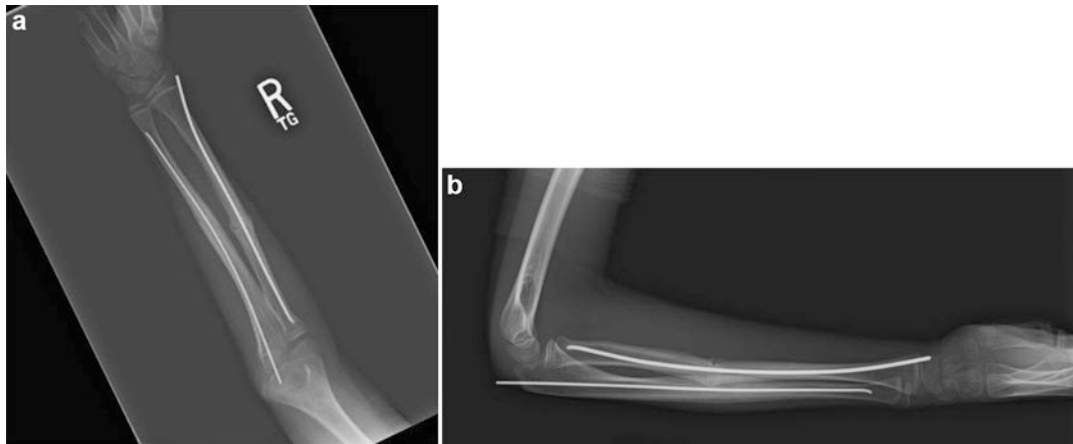


Fig. 4 Radiographs of the right radius and ulna at approximately 3 months status postinjury demonstrate maintenance of the reduction with callous formation

Fig. 5 Radiographs approximately 6 months status post initial surgical fixation after subsequent removal of hardware



limb proximally), but inserted 180° rotated for ease of initial insertion. Once passed, the nail can be rotated 180° to restore the radial bow.

2. Obtain intraoperative radiographs as the IM nail is advanced and adjust tip of nail to avoid penetrating cortex
3. Do not use too large an intramedullary nail – increases difficulty of passing nail across fracture site. The nail diameter should be approximately 60–80% of the medullary canal diameter.
4. Radial nail start point should be proximal to the distal radius physis. Can insert from radial distal radius (interval between 1st and 2nd extensor compartment) or dorsal distal radius (just proximal to Lister's tubercle). With a radial start point, the branches of the superficial branch of the radial nerve should be visualized and protected and a soft tissue protector should be utilized prior to opening the radial cortex with the drill. When placing the nail dorsally, the interval between the 2nd and 3rd extensor compartment is utilized. Ensure that the distal aspect of the nail, once cut, is out of extensor compartment to prevent rubbing against the tendons and decrease risk of tendon irritation or rupture.
5. Ulnar nail inserted from proximal to distal via olecranon apophysis or more lateral start point
6. Both Titanium and stainless steel elastic nails are available. Titanium nails are more flexible, which facilitates easier insertion and rotation. Stainless steel elastic nails are more rigid, which can increase stability during healing of the forearm fractures.

8 Outcome Clinical Photos and Radiographs

See Figs. 4 and 5.

9 Avoiding and Managing Problems

1. Avoid multiple attempts at closed reduction intraoperatively – can increase risk for postoperative compartment syndrome. If unsuccessful after three attempts, perform open reduction.
2. Cut IM nail short enough to avoid tissue irritation distally in the radius and posteriorly at level of olecranon
3. If only one bone is stabilized with intramedullary fixation, close follow up will be necessary to evaluate for displacement in the other fractured bone.
4. Postoperative immobilization choice at discretion of surgeon based on fracture stability and patient characteristics.

10 Cross-References

- [Midshaft Both Bone Forearm Fracture: Plate Fixation](#)
- [Midshaft Both Bone Forearm Fracture: Single Bone Fixation](#)
- [Proximal Third Both Bone Forearm Fractures](#)

References and Suggested Reading

- Blackman AJ, Wall LB, Keeler KA, Schoenecker PL, Luhmann SJ, O'Donnell JC, Gordon JE (2014) Acute compartment syndrome after intramedullary nailing of isolated radius and ulna fractures in children. *J Pediatr Orthop* 34(1):50–54
- Fernandez FF, Egnolf M, Carsten C, Holz F, Schneider S, Wentzensen A (2005) Unstable diaphyseal fractures of both bones of the forearm in children: plate fixation versus intramedullary nailing. *Injury* 36:1210–1216
- Waters PM, Bae DS (2012) Forearm fractures. In: *Pediatric hand and upper limb surgery*. Lippincott Williams & Wilkins Kluwer, Philadelphia, pp 391–405

Midshaft Both Bone Forearm Fracture: Single Bone Fixation

Jenifer Powers and Scott Rosenfeld

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Abstract

Both bone forearm fractures are common injuries in children. While some can be treated with closed reduction and casting, more unstable fractures may require operative treatment utilizing internal fixation. The amount of radius and ulna deformity that can be tolerated in the sagittal and coronal planes diminishes with age. Rotational deformity can never be accepted. Closed reduction and *flexible intramedullary nailing* of both bones has been a long-accepted treatment method in such injuries. Here we will discuss closed reduction and single bone fixation in the setting of

both bone forearm fractures. In many cases, fixation of a single bone provides adequate stability when an acceptable reduction of both bones can be obtained. Instrumentation of only a single bone may decrease operative time and the amount of fluoroscopy used. Given the relative ease of instrumentation of the ulna, it is our preference to fix the ulna and rely on a well-molded cast to attain and maintain the radial bow. Postoperative management does not differ from fixation of both bones and relies on an appropriately molded cast and close follow up.

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1 Brief Clinical History

We present a case of an otherwise healthy 10-year-old male who jumped from swing and sustained a closed midshaft *both bone forearm fracture*. An attempt was made at closed reduction and casting, however, at 1-week follow-up he was found to have loss of reduction. He therefore went on to operative fixation of his forearm fractures.

Fig. 1 AP radiograph of the forearm demonstrating displaced fractures of the midshaft of the radius and ulna



Fig. 2 Lateral radiograph of the forearm demonstrating displaced fractures of the midshaft of the radius and ulna

2 Preoperative Clinical Photos and Radiographs

1. AP forearm radiograph demonstrating displaced *midshaft fractures of the radius and ulna*
2. Lateral forearm radiograph demonstrating displaced midshaft fractures of the radius and ulna (See Figs. 1 and 2)

3 Preoperative Problem List

1. Displaced midshaft radius fracture
2. Displaced midshaft ulna fracture

4 Treatment Strategy

The goals of surgical intervention include restoration of radial and ulnar length and rotation as well as maintenance of the radial bow while minimizing operative time and risk of compartment syndrome.

5 Basic Principles

The basic principles for treating *both bone forearm fractures* with single bone fixation are the same as those for both bone fixation. While it is ultimately at the discretion of the provider, surgical indications for both bone forearm fractures generally include greater than 20° of diaphyseal angulation or a change of more than 10–15° in a cast on serial radiographs (Dietz et al. 2010). It is important to restore both length and rotation. Rotational alignment is considered normal when the radial styloid and bicipital tuberosity are 180° from each other on an AP radiograph of the forearm. It is also important to minimize the number of attempts made at passing the flexible nail, as there is an increased risk of compartment syndrome with multiple attempts at passage.

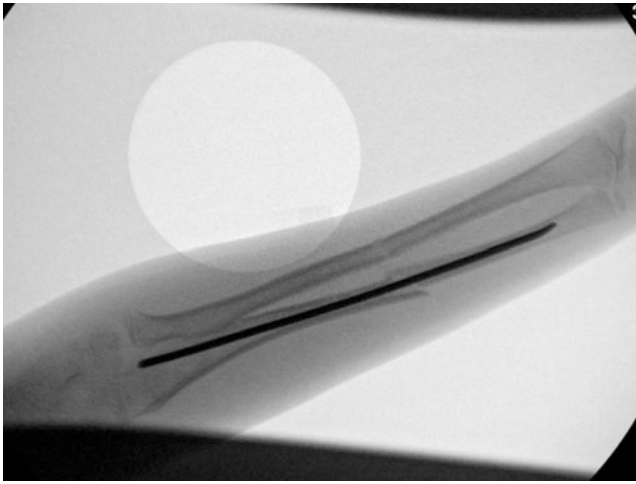


Fig. 3 Intraoperative fluoroscopic AP view demonstrating restoration of radial and ulnar length, as well as appropriate rotation with the tip of the radial styloid 180 degrees from the bicipital tuberosity

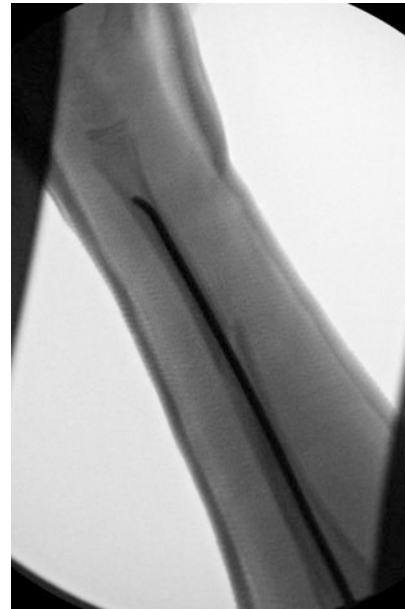


Fig. 5 Intraoperative fluoroscopic lateral view demonstrating acceptable alignment



Fig. 4 Intraoperative fluoroscopic AP view after casting showing restoration of the radial bow after placement of an intramedullary mold

6 Images During Treatment

1. Intraoperative fluoroscopic AP view showing restoration of radial and ulnar length, and appropriate rotation with the tip of the radial styloid 180° from the bicipital tuberosity

2. Intraoperative fluoroscopic AP view in the cast showing restoration of radial bow after placement of intramedullary mold
3. Intraoperative fluoroscopic lateral view
4. AP radiograph 6 weeks post operatively demonstrating maintenance of rotation and radial bow
5. Lateral radiograph 6 weeks post operatively (See Figs. 3, 4, 5, 6, and 7)

7 Technical Pearls

Because it is generally easier to both place and subsequently remove implants from the ulna than the radius, our preference, when possible is to instrument the ulna only. Additionally, not instrumenting the radius decreases the risk of irritation of the superficial radial nerve and the tendons about the distal radius. Placement of the ulnar nail can be performed through the tip of the olecranon or a lateral approach through anconeus. Fixation can be performed utilizing either a large Steinman pin or a flexible intramedullary nail. Our preferred method is a flexible nail through the lateral approach as it seems that the laterally placed ulnar nail is less symptomatic than those placed at the tip of the olecranon. A small incision is made just distal to the olecranon physis and just off the posterolateral ridge of the olecranon. Once the correct position is confirmed using fluoroscopy, an awl is used to make a

Fig. 6 AP forearm radiograph 6 weeks post operatively demonstrating maintenance of rotation and radial bow



Fig. 7 Lateral forearm radiograph 6 weeks post operatively demonstrating maintained alignment



starting hole for the nail. Unbending of this nail prior to insertion is helpful. Instrumentation crosses the fracture site and stops just short of the distal ulnar physis. This implant should assure that the ulnar border of the forearm is restored to its straight alignment. The radial bow is then restored with an interosseous mold. While previous studies have failed to show that appropriate cast molding minimizes the chance of loss of reduction (Dietz et al. 2010), the authors believe that a good interosseous mold is essential to reconstituting the radial bow and minimizing fracture displacement.

When instrumenting the radius only, we use a physseal sparing approach through the floor of the first dorsal compartment. A small incision is made just proximal to the distal radius physis and over the first dorsal compartment. Care is taken to protect the superficial radial nerve. The tendons within the compartment are retracted and an awl is again used to create our starting point. We do place a bend in this nail as to help recreated the radial bow.

When choosing the appropriate sized nail, it should fill approximately 40% of the canal. This is often a 2.0 or 2.5 mm flexible nail. Our preference is a titanium nail as it is easier to pass across the fracture site.

When placing the long arm cast it is important to obtain a good interosseous mold along the entire length of the forearm. The authors prefer to cast the forearm in neutral rotation with the elbow flexed less than 90°. After performing the mold, fluoroscopic images should be taken in the cast to

confirm restoration of radial bow. Following this, the cast should be bivalved to decrease the risk of compartment syndrome. The bivalve is less likely to result in loss of reduction when the cuts are made through the volar and dorsal surface of the cast.

8 Outcome Clinical Photos and Radiographs

1. AP radiograph 3 months postoperatively
2. Lateral radiograph 3 months postoperatively (See Figs. 8 and 9)

This patient went on to heal his fracture by 3 months without complication and returned to activity at that time. He did not present back for removal of implants. It is generally our recommendation that the implants be removed around 1 year post operatively. If left in too long they can be difficult to remove, but if removed too soon, the patient is at increased risk of refracture.



Fig. 8 AP forearm radiograph 3 months post operatively demonstrating complete healing



Fig. 9 Lateral forearm radiograph 3 months post operatively demonstrating complete healing

9 Avoiding and Managing Problems

Several studies have shown increased risk of loss of reduction and need for rereduction when performing single bone fixation compared to both bone fixation (Lee et al. 2002). In our experience, close follow up is essential to ensuring that reduction is not lost and intervening early if it is. Postoperatively, patients are placed into a long arm cast with care taken to obtain a good interosseous mold. Patients follow up 1 week postoperatively for an alignment check and then again at 4 weeks. If there is adequate callus at that time, they are transitioned to a below elbow cast for another 4–6 weeks. If there is a loss of reduction of the radial bow this can often be corrected with a placement of a new cast with remodeling of the interosseous membrane. Intraoperatively, after fixation of the ulna, the arm should be manipulated to reduce the radius. If the radius is irreducible, then reduction and fixation of the radius should be performed as well (Flynn and Waters 1996). Finally, because this treatment method

relies on soft tissue tension around the noninstrumented bone, grade 1 open injuries are less likely to be successful with single bone fixation given the amount of tissue stripping that occurs with an open injury. Starting the intramedullary nail laterally through anconeus leads to less symptoms related to implant prominence when compared to entering through the tip of the olecranon. One final risk associated with intramedullary fixation of forearm fractures is compartment syndrome. This is believed to be related to the number of attempts to pass the wire. By only instrumenting one bone, this may decrease the risk of compartment syndrome and therefore be one theoretical advantage to single bone fixation (Dietz et al. 2010).

10 Cross-References

- [Midshaft Both Bone Forearm Fracture: Intramedullary Rod Fixation](#)
- [Midshaft Both Bone Forearm Fracture: Plate Fixation](#)

References and Suggested Reading

- Dietz JF, Bae DS, Reiff E et al (2010) Single bone intramedullary fixation of the ulna in pediatric both bone forearm fractures: analysis of short-term clinical and radiographic results. *J Pediatr Orthop* 30:420–424
- Flynn JM, Waters PM (1996) Single bone fixation of both bone forearm fractures. *J Pediatr Orthop* 16:655–659
- Lee S, Nicol RO, Stott NS (2002) IM fixation for pediatric unstable forearm fractures. *Clin Orthop* 402:245–250

Distal Third Radius Fractures with an Intact Ulna

Julie Balch Samora

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Abstract

Distal third radius fractures are common injuries in childhood and can often be treated nonoperatively with closed reduction and casting. Fracture management becomes slightly more challenging when the radius is displaced and the ulna is either nondisplaced or intact. Sometimes, isolated distal third radius fractures cannot be close reduced, and even when closed reduction is achieved, the fracture may subsequently displace. Therefore, close monitoring is required for early detection of displacement. Cast wedging can improve alignment, but patients may ultimately require operative intervention. Techniques include closed reduction and percutaneous pinning, open reduction with internal fixation using plates and screws, and intramedullary fixation.

1 Brief Clinical History

The patient is a 10-year-old female who sustained an injury to her left wrist while “Rip Sticking” and was placed in a sugartong splint by an outside provider (Fig. 1). She followed up in the pediatric orthopedic clinic 1 week after her injury. On exam, she had some swelling about her wrist, but no visible deformity. She was placed in a long-arm molded cast and was scheduled to follow-up in 1 week for close evaluation. She presented at 14 days with increasing angular deformity (Fig. 2) and was indicated for closed versus open reduction and stabilization.

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Fig. 1 Initial presentation to orthopedic clinic 1 week after injury with AP (a) and lateral (b) radiographs demonstrating a mildly displaced distal third radius fracture and a nondisplaced distal third ulna fracture

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

None.

4 Treatment Strategy

Wedging could have been attempted in this scenario, but given the intact ulna and delayed presentation, it would likely not have been successful. We did discuss the possibility of repeat reduction and casting, but after discussing risks and benefits with the family, closed reduction and percutaneous pinning was chosen. In the operating room, the distal radius fracture reduced fairly easily with manipulation; the ulna fracture was completed with this technique (Fig. 3). The decision of Kirschner wire placement (distal or proximal to the physis) is surgeon- and fracture-dependent. If there is adequate space, it is preferable to place the pin proximal to the physis, but occasionally the pin must traverse the growth plate to obtain proper stability. Smooth



Fig. 2 At the following orthopedic visit, AP (a) and lateral (b) radiographs demonstrate increased volar apex deformity of the distal third radius fracture

pins should be utilized, crossing the physis only once in order to reduce the risk of physeal arrest. Placing a small incision, spreading the soft tissues, and utilizing a soft tissue protector while advancing the pin helps ensure protection of the radial sensory nerve. Often one larger Kirschner wire (size 0.062 inch or 2 mm) will suffice, but stability can be tested in the operating room, and a decision to add further fixation is made on a case-by-case basis. We apply a long-arm cast with a gentle dorsal mold, pull the pin at 4 weeks, and often transition into a short arm cast for two more weeks.

5 Basic Principles

Although many distal radius fractures may be treated with closed reduction and cast immobilization, close follow-up is essential, particularly with the isolated radius fractures. Loss of reduction in distal radius fractures occurs approximately 30% of the time (Proctor et al. 1993; Zamzam and Khoshhal 2005; Miller et al. 2005), but isolated radius fractures have been found to need re-manipulation 91% of the time (Gibbons et al. 1994). Risks for loss of reduction include a cast index of greater than 0.7, incompletely reduced fractures

Fig. 3 AP (a) and lateral (b) intraoperative fluoroscopy images demonstrate closed reduction and percutaneous pinning, with the pin start site proximal to the distal radius growth plate

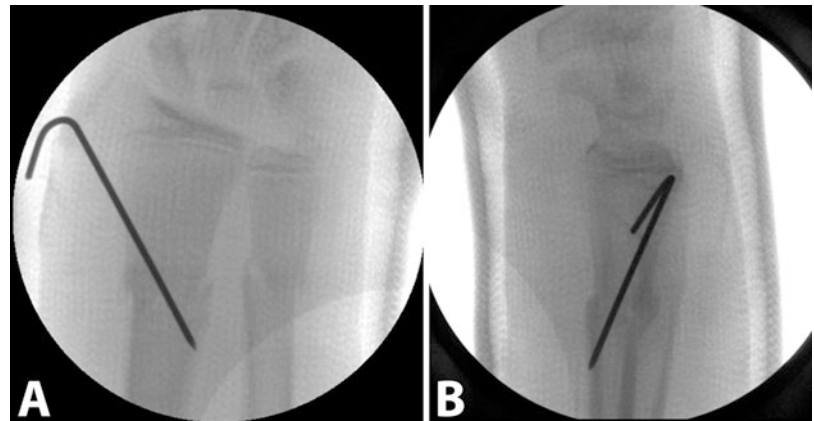


Fig. 4 A 12-year-old female with a displaced radial shaft fracture with distal third ulna buckle fracture (a, b) underwent closed reduction and casting and presented to the orthopedic clinic 10 days later with further displacement, shortening, and loss of the radial bow (c, d). She was indicated for surgical intervention, and necessitated open reduction at the fracture site, as closed reduction attempts were unsuccessful. AP (e) and lateral (f) fluoroscopy films demonstrate placement of 2 mm titanium elastic nail, with the start site proximal to the growth plate



(i.e., residual displacement and/or angulation following manipulation), degree of initial fracture displacement/obliquity (bayonet apposition, greater than 50% translation, and greater than 30° angulation), muscle atrophy, and

resolution of initial soft tissue swelling while in the cast. Complete metaphyseal fractures in children older than 10 are at a very high risk of loss of reduction (Miller et al. 2005).



Fig. 5 Radiographs at 4 weeks (**a, b**) demonstrate callus formation and overall acceptable alignment. The pin was pulled at this visit and a short-arm cast was applied for 2 more weeks



Fig. 6 Radiographs taken 4 years later for a different injury demonstrate good remodeling and overall alignment

6 Images During Treatment

See Fig. 3(a), (b).

7 Technical Pearls

If a radius fracture necessitates surgical intervention, options include repeat reduction and casting, closed reduction and pinning, open reduction and internal fixation with plates/screws, or flexible intramedullary nails. The decision must

assimilate the fracture location, surgeon experience, patient age, and patient/family preferences.

Open reduction and internal fixation with plates and screws does require a more extensive exposure and requires a decision to subsequently remove the hardware. Removal of plate and screw constructs is associated with a risk of re-fracture.

Intramedullary fixation requires attention to the growth plate, with initiation of the start site proximal to the physis. The start site may either be between the third and fourth extensor compartments or on the radial aspect of the metaphysis, with care to protect the radial sensory nerve and the dorsal extensor tendons. If the fracture is fairly distal, a more dorsal starting site is easier to prevent displacement, but is associated with extensor tendon ruptures. One must also place a three-point bend to help re-create the radial bow before inserting the rod, although often, the bend is reduced with advancement into the medullary canal. While drilling the start site, a tissue protector is utilized and the drill is directed nearly in line with the radius to open the cortical entrance. Care should be taken not to drill the second cortex, or passage of the nail may be difficult. Repeated closed reduction attempts and repeated attempts at passage of the intramedullary nail can lead to compartment syndrome, so one should have a low threshold to open the fracture site if encountering difficulty (see Fig. 4).

8 Outcome Clinical Photos and Radiographs

See Figs. 5(a), (b) and 6.

9 Avoiding and Managing Problems

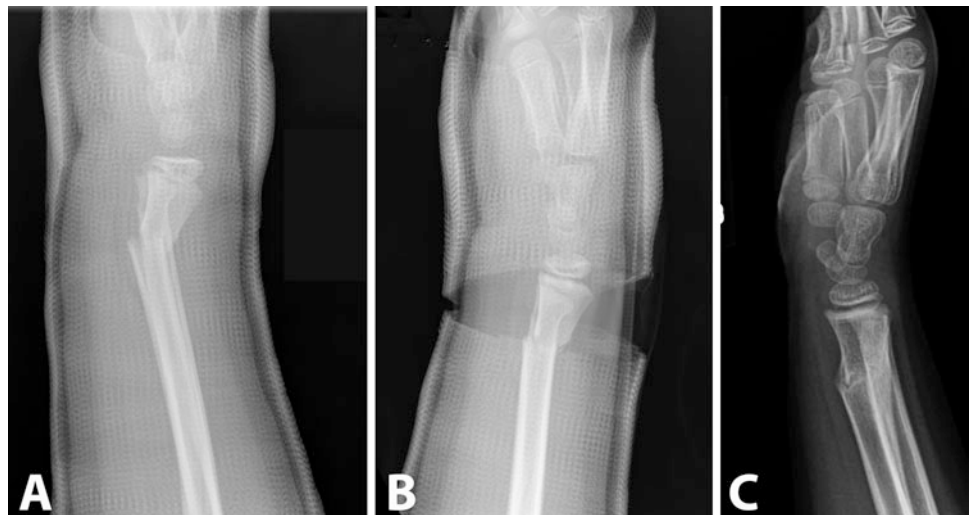
The best chance to avoid loss of reduction is to apply a well-molded cast without too much cast padding. These fractures tend to displace with apex volar and ulnar angulation (See Fig. 7), and therefore a good dorsal mold with the wrist in ulnar deviation is paramount.

If a reduction is lost, cast wedging remains a good technique that may avert surgical intervention (Samora et al. 2014). The better the cast index, the greater success for wedging. We try to wedge the cast within the first 1 to 2 weeks, but we have had success as late as 3 weeks. The cast is cut nearly circumferentially, leaving a bridge less than one-fourth of the circumference (Fig. 8). The size of wedge depends on the amount of correction needed and the placement of the cut in relation to the fracture. If it is unclear where the fracture is, one can always place a radiographic marker

Fig. 7 An example of a distal third radius fracture (a, b) with minimal ulnar involvement that was reduced nicely (c), but because the cast was not well applied, it subsequently lost reduction by the 1 week clinic appointment (d, e)



Fig. 8 Sometimes, a cast can be wedged to improve alignment. This 7-year-old patient presented to clinic 1 week after closed reduction and casting with loss of reduction (a). Wedging was performed acutely (b), and at 5 weeks, radiographs demonstrated overall acceptable alignment (c).



and then obtain either an AP or lateral image to ensure proper position of the wedge before cutting the cast.

Complications of surgical intervention can include infection, nonunion, malunion, tendon rupture, radial sensory nerve irritation, compartment syndrome, re-fracture, stiffness, hypertrophic scar formation, and hardware irritation. Compartment syndrome can be avoided by setting a timer when attempting a closed reduction and flexible

intramedullary nailing. We have the circulating nurse set the timer for 10 min; if we cannot reduce and pass the rod in this time, we will open the fracture site. Furthermore, we only attempt at most three passages across the fracture site before opening. Most of these problems can be avoided with good surgical technique, but patients and families should be aware of these potential outcomes.

10 Cross-References

- [Compartment Syndrome of the Hand](#)
- [Midshaft Both Bone Forearm Fracture: Intramedullary Rod Fixation](#)
- [Physeal Fracture of the Distal Radius](#)
- [Proximal Third Both Bone Forearm Fractures](#)
- [Volar Shear Fractures of the Distal Radius](#)

References and Suggested Reading

Gibbons CL, Woods DA, Pailthorpe C, Carr AJ, Worlock P (1994) The management of isolated distal radius fractures in children. *J Pediatr Orthop* 14:207–2010

- Miller BS, Taylor B, Widmann RF, Bae DS, Snyder BD, Waters PM (2005) Cast immobilization versus percutaneous pin fixation of displaced distal radius fractures in children: a prospective, randomized study. *J Pediatr Orthop* 25:490–494
- Proctor MT, Moore DJ, Paterson JM (1993) Redisplacement after manipulation of distal radial fractures in children. *JBJS Br* 75:453–454
- Samora JB, Klingele K, Beebe A, Kean J, Klamar J, Beran M, Willis L, Samora W (2014) Is there still a place for cast wedging in pediatric forearm fractures? *J Pediatr Orthop* 34(3):246–252
- Zamzam MM, Khoshhal KI (2005) Displaced fracture of the distal radius in children: factors responsible for redisplacement after closed reduction. *J Bone Joint Surg Br* 87:841–843

Management of Late Displacement (>5 days) of a Previously Reduced Salter II Distal Radius Fracture

Jennifer M. Bauer and Jennifer M. Ty

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Abstract

A 12-year-old boy sustained a left Salter-Harris type II distal radius physeal fracture. The fracture underwent successful closed reduction but was noted to have displacement at 10 days. Given his age and the type of fracture, remodeling was anticipated, and the fracture was not remanipulated at that time due to the increased risk of physeal injury with late reduction attempts. The fracture went on to union with closed treatment and was noted to have evidence of continued growth and remodeling at last follow-up, with good clinical and radiologic outcomes.

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1 Brief Clinical History

A 12-year-old otherwise healthy right-hand dominant boy fell onto his outstretched left arm after tripping while playing kickball. He was brought immediately to the emergency room for evaluation. He complained of pain and deformity to his wrist, as well as tingling to his thumb, index, and long fingers. On exam, the left wrist had obvious dorsal displacement with intact motor function to the hand but decreased sensation in the distal median nerve distribution.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

Fig. 1 Initial AP and lateral injury films showing displaced left distal radius Salter-Harris II fracture with an associated ulnar styloid fracture



3 Preoperative Problem List

1. Salter-Harris type II distal radius fracture
2. Ulnar styloid fracture
3. Age of patient, 4 years estimated growth remaining
4. Choice of fixation/immobilization
5. Median nerve neuropraxia

4 Treatment Strategy

Given the acuity of presentation, 4-year growth potential remaining, and Salter-Harris II fracture pattern, the decision was made to treat with closed reduction and immobilization in the emergency room under conscious sedation. Prompt reduction is indicated to relieve pressure off the median nerve at the level of the volar metaphyseal spike.

Reduction in the operating room under general anesthesia with muscle relaxation and with the possibility of smooth K-wire for transphyseal fixation from the styloid was also considered. Many authors encourage a “gentle reduction” or only one attempt at a reduction maneuver to prevent injury to the growth plate. Types of immobilization include splinting or casting, above or below elbow immobilization, and plaster of Paris versus fiberglass casting. Each of these options has been shown to be effective.

After reduction, this patient’s alignment was initially held in a sugar-tong plaster mold to control pronosupination. The

splint was then overwrapped immediately into a long arm fiberglass cast for durability.

5 Basic Principles

1. The majority of distal radius physeal fractures are type I or II Salter-Harris fractures, which can be treated with closed reduction if displaced and immobilization. Type III and IV fractures of the distal radius are rare but if unable to be adequately reduced would warrant open reduction and fixation to align the joint surface. Type V Salter-Harris fractures may appear benign at first and need no reduction but can be associated with physeal arrest and thus should be managed expectantly.
2. Acceptable alignment is controversial, but dorsal angulation up to 20° in patients over 10 years old is widely accepted, given remodeling potential, and up to 30° in children younger than 10.
3. Well-molded short or long arm immobilization has been shown to maintain reduction equally well in several randomized controlled trials of physeal and distal third forearm fractures (Webb et al. 2006; Bohm et al. 2006). There is no consensus on the need to bivalve or univalve a cast or in which plane to do so.
4. Close follow-up for the first 2 weeks is needed to monitor alignment, with a total immobilization time of 4–6 weeks.

Fig. 2 AP and lateral immediate postreduction radiographs show acceptable alignment. Plaster sugar-tong splint under fiberglass overwrap is visible



Fig. 3 Reduction maintained at 4-day follow-up, with complete resolution of median neuropathy. This follow-up is made within 5 days to allow re-manipulation if needed. While most authors agree re-manipulation should be done within 1 week, there is no specific evidence as to this cut-off



6 Images During Treatment

See Fig. 2.

7 Technical Pearls

1. Longitudinal traction is useful to help avoid physeal injury on initial reduction. Some favor the use of pre-reduction finger traction to allow muscles to relax and ligamentotaxis to aid the reduction if the child can tolerate this.
2. A well-molded cast includes two-point pressure precisely placed – 1 volar at the metaphysis, 1 dorsal at the epiphysis – along with appropriate cast index.
3. Physeal injury in distal radius physeal fractures is rare (Houshian et al. 2004), but repeat reduction attempts are thought to contribute to growth arrest. Compression-type injuries may be associated with arrest (Lee et al. 1984).

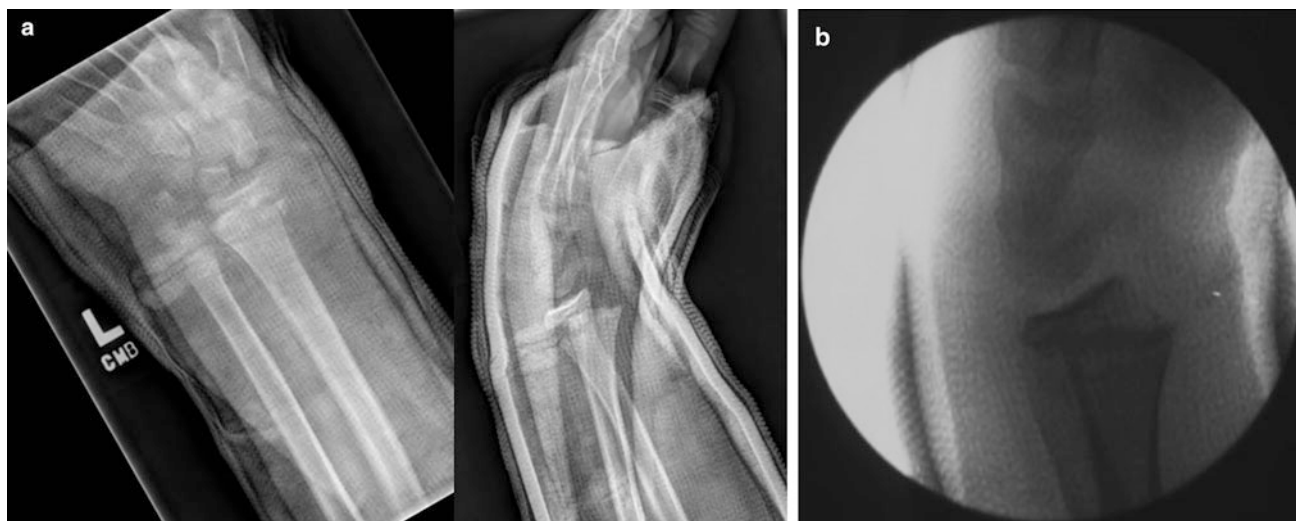


Fig. 4 (a) Loss of reduction was noted at 10-day follow-up with further dorsal displacement. (b) Alignment was confirmed on lateral-view in-office fluoroscopy. As it was later than 7 days, no repeat reduction

attempt was made. The fracture was treated with placement of a new long arm cast with a gentle mold to maintain what alignment remained and to protect against any further loss

Fig. 5 Radiographs at 4-week follow-up. Alignment is unchanged, and long arm cast was discontinued to short arm cast for another 3 weeks



8 Outcome Clinical Photos and Radiographs

See Figs. 3, 4, 5, and 6.

9 Avoiding and Managing Problems

1. Early follow-up after closed reduction is key to allow for safe re-manipulation of the fracture if interval loss of reduction occurs.
2. A physeal crush type V Salter-Harris fracture may be initially missed but is at high risk for physeal arrest and should be followed closely.
3. Late re-manipulation and multiple manipulation attempts cause an increased risk to the physis (Lee et al. 1984) and should be avoided.
4. Distal radius physeal fractures have excellent remodeling potential and clinical forgiveness, with 92% of those over 11 years old achieving complete remodeling (Houshian et al. 2004). Cannata et al. found that a growth arrest up to 1 cm was well tolerated. (Cannata et al. 2003).



Fig. 6 Radiographs at 2 months (a), 7 months (b), and 12 months (c) after injury shows significant remodeling which is anticipated to continue as the growth plate remains open. An ulnar styloid nonunion is noted

5. Long-term follow-up of distal radius physeal fractures ensures detection of physeal arrest, which is reported at a rate up to 7% (Lee et al. 1984). If an arrest occurs, ulnar epiphysiodesis, ulnar shortening osteotomy, or radial lengthening osteotomy may be necessary to avoid ulnar positive variance and subsequent complications, or a physeal bar resection may be performed if anatomically possible. An example of a physeal arrest in the setting of a close-reduced type II fracture is shown in Fig. 7. As this was noted prior to development of significant ulnar positive variance, and there was less than 1 year of expected growth remaining, this was successfully treated with an ulnar epiphysiodesis.
6. Transient median nerve sensory neuropraxia must be distinguished from acute carpal tunnel syndrome, the latter of which is associated with increasing pain and progressive sensory deficit, followed by recurrent median nerve branch motor weakness. Acute carpal tunnel syndrome is a surgical urgency requiring open nerve decompression if fracture reduction does not reverse the symptoms. In these cases, the fracture should be percutaneously pinned to obviate the need for a subsequently tightly molded cast.
7. Ulnar styloid nonunions are very common and usually asymptomatic. Occasionally, overgrowth can be noted with symptoms of ulnar impingement that responds to excision and TFCC repair if needed.



Fig. 7 MRI of a 15-year-old male's wrist, 9 months status-post type II Salter-Harris II distal radius fracture

10 Cross References

- [Distal Third Radius Fractures With an Intact Ulna](#)
- [Physeal Fracture of the Distal Radius](#)

References and Suggested Reading

- Bohm ER, Bubbar V, Yong Hing K, Dzus A (2006) Above and below-the-elbow plaster casts for distal forearm fractures in children. A randomized controlled trial. *J Bone Joint Surg Am* 88(1):1–8
- Cannata G, De Maio F, Mancini F, Ippolito E (2003) Physeal fractures of the distal radius and ulna: long-term prognosis. *J Orthop Trauma* 17(3):172–179
- Houshian S, Holst AK, Larsen MS, Torfing T (2004) Remodeling of Salter-Harris type II epiphyseal plate injury of the distal radius. *J Pediatr Orthop* 24(5):472–476
- Lee BS, Esterhai JL Jr, Das M (1984) Fracture of the distal radial epiphysis: characteristics and surgical treatment of premature post-traumatic epiphyseal closure. *Clin Orthop Relat Res* 185:90–96
- Webb GR, Galpin RD, Armstrong DG (2006) Comparison of short and long arm plaster casts for displaced fractures in the distal third of the forearm in children. *J Bone Joint Surg Am* 88(1):9–17

Galeazzi Fracture: Distal Radius Fracture with Dislocated Distal Radioulnar Joint

Deborah Bohn

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Abstract

A Galeazzi fracture is a radius shaft fracture accompanied by disruption of the distal radio-ulnar joint (DRUJ). These fractures are uncommon in children and may be atypical compared to those in adults. Diagnostic vigilance is important, as these injuries are frequently missed (Walsh et al. 1987). The classic injury pattern as attributed to Galeazzi is an unstable fracture of the radius shaft at the junction of the middle and distal thirds plus injury to the distal radioulnar joint, usually the triangulo-fibro-cartilage complex (TFCC). However, due to the unique features of the physes in the skeletally immature patient, the mode of failure is more often through bony elements (Landfried et al. 1991). Ultimately, restoration of normal anatomy is imperative in the treatment of these injuries. Failure to do so may result in loss of forearm rotation, instability of the DRUJ, or chronic wrist pain.

1 Brief Clinical History

Galeazzi fracture and its variations typically occur in older children with moderate-energy trauma (Letts and Rowhani 1993). Sports-related injury is common; a fall on the outstretched hand or direct blow by another player falling on the patient's limb. Obvious deformity is present with angulation through the forearm and either dorsal or volar prominence of the head of the ulna at the wrist. Patients are less able to move their fingers than in distal radius fracture due to stretch of the tendons across the deformity. Dedicated forearm and wrist x-rays should be obtained. True posterior-anterior (PA) and lateral radiographs are often difficult to obtain due to inability of the patient to rotate the forearm. In fact, inability to obtain satisfactory standard views may be a clue to the DRUJ injury. Open injury and nerve injury are rare.

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Fig. 1 Injury radiographs of a 13-year-old boy who injured his wrist playing hockey. PA view of a distal radius shaft short oblique fracture. Note the defect where the ulna styloid should be, representing a Salter-Harris type IV fracture. The styloid fragment is seen as a double density overlying the ulna, just proximal to the physis

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4 and 5.

3 Preoperative Problem List

- Displacement or angulation of the radius shaft fracture
- Incongruity of the DRUJ
- Interposed soft tissue structures preventing reduction of the DRUJ
- Persistent instability of the DRUJ after stabilization of the radius

4 Treatment Strategy

- Correct radius alignment
- Stabilize the radius fracture if needed to get anatomic reduction



Fig. 2 Injury radiographs of the patient in figure 1. Oblique view showing the ulna styloid fragment

- Assess DRUJ for anatomic alignment, stability, and full forearm rotation
- Repair structures as necessary to stabilize DRUJ
- Immobilize forearm for 6 weeks in a long arm cast

5 Basic Principles

The primary problem is deformity of the radius, so this should be addressed first. This needs to be corrected rigorously enough to obtain proper articulation of the head of the ulna in the distal radius sigmoid notch. If the radius is not realigned, there is likely to be persistent or chronic instability of the DRUJ or poor forearm rotation. Children treated with closed reduction and casting alone may have poor forearm motion at final follow up (Letts and Rowhani 1993), though a recent series shows good results with closed reduction and casting, even when the DRUJ injury went unrecognized (Eberl et al. 2008). Rigid fixation of the radius is recommended if anatomic closed reduction cannot be obtained.

Once the radius deformity is corrected, the DRUJ should be assessed using the image intensifier (C-arm). If it is well-aligned (no widening on the PA, no subluxation on the lateral, no widely displaced ulna styloid fracture) the DRUJ should



Fig. 3 Injury radiographs of the patient in figures 1 and 2. Lateral view showing apex volar angulation of the radius. Note: the distal radio-ulnar articulation is not aligned in any of the views



Fig. 4 Injury radiographs of a 12-year-old girl who fell off her bicycle. PA view of a distal radius shaft fracture and Salter-Harris type I fracture of the distal ulna with wide displacement. The circular structure overlying the ulna is the distal ulna epiphysis.

be stressed to determine if there is persistent instability. If stable, no further intervention is necessary. If DRUJ instability exists, determine whether there is bony or soft tissue injury. Ulna styloid base fractures should be fixed and often require open reduction due to interposed periosteum, extensor tendons, or joint capsule. Instability with pure soft tissue injury may be treated closed, or as in the adult, with repair of the injured structures. This is controversial, as many children have good results with closed management of the soft tissue injury but some do not (Eberl et al. 2008; Walsh et al. 1987). Arthroscopy may be useful for TFCC tear repair but foveal avulsions are not always visible through the arthroscope in the face of an intact triangulofibrocartilage (TFC) disk.

Postoperative treatment should include immobilization of the forearm in supination for 4–6 weeks followed by range of motion (ROM), strengthening and gradual return to activities as tolerated. Full, unrestricted activities are allowed by 3 months.

6 Images During Treatment

See Figs. 6, 7 and 8.

7 Technical Pearls

- Radius fixation with percutaneous pins can be technically difficult. The fracture is usually too far proximal for standard retrograde K-wire fixation (although fixation may be accomplished from non-standard entry points). Intramedullary fixation often yields an inadequate reduction due to the width of the intramedullary space. Plating may be necessary, bearing in mind that even small fragment plates may not allow for enough screws distal to the fracture while still avoiding the physis. Mini fragment plates may be necessary.
- Percutaneous pinning of the ulna styloid in a correctly reduced position is fraught with technical difficulty and error. Open reduction and fixation under direct vision more easily and accurately accomplishes the task. Pinning across the distal radioulnar joint is discouraged because it does not address the primary problem causing DRUJ instability.
- During fixation of the ulna styloid or repair of the TFCC, it is tempting for the assistant to extremely rotate the forearm to bring the ulna styloid into view. However, this tensions the soft tissues and displaces the styloid fragment. If the fragment is difficult to reduce, try rotating the forearm into neutral.



Fig. 5 Injury radiographs of the patient in figure 4. Lateral view shows 100% displaced and angulated radius shaft fracture and malalignment of the distal radio-ulnar joint



Fig. 7 Postoperative PA view of the patient in Figs. 4 and 5, 4 months after injury. In order to reduce the DRUJ, the patient was casted in full supination. Note that there is healing of the radius shaft fracture but persistent incongruity of the DRUJ. The patient had significant loss of pronation, likely due to rotational malunion of the ulna



Fig. 6 Postoperative PA radiograph of the patient in Figs. 1, 2 and 3. There has been reduction of the radius fracture with a retrograde K-wire and suture anchor reducing the ulna styloid fracture. The distal radio-ulnar joint appears congruent

Fig. 8 Postoperative lateral view of the patient in Figs. 4 and 5, 4 months after injury. In order to reduce the DRUJ, the patient was casted in full supination. Note that there is healing of the radius shaft fracture but persistent incongruity of the DRUJ. The patient had significant loss of pronation, likely due to rotational malunion of the ulna





Fig. 9 Postoperative PA radiograph of the patient in Figs. 1, 2 and 3, 2 months after injury with healing of the radius shaft fracture. Note there is evidence of tethering of the far ulnar side of the distal ulna physis by the nonabsorbable stitch.



Fig. 10 Postoperative PA radiograph of the patient in Figs. 1, 2 and 3, 4 months after injury with healing of the radius shaft fracture. Note there is evidence of tethering of the far ulnar side of the distal ulna physis by the nonabsorbable stitch. Surgery was performed to cut the stitch

8 Outcome Clinical Photos and Radiographs

See Figs. 9, 10, 11, 12 and 13.

9 Avoiding and Managing Problems

The best way to avoid problems is to recognize and treat all injuries appropriately at the index encounter as anatomic alignment yields better results (Rettig and Raskin 2001). A common mistake is to assume that angulation of the radius will remodel. However, these injuries are relatively far from the physis, may be malrotated, and patients tend to be approaching skeletal maturity at the time of injury.

When persistent malunion of the radius causes chronic DRUJ pain or instability, correction of the bony deformity is imperative for success of soft tissue reconstructions. In fact, radius corrective osteotomy often renders the DRUJ stable and soft tissue repair or reconstruction may not be necessary.

In the case of transphyseal ulna styloid fracture, radiographic surveillance is recommended to assess for growth arrest or tethering. Various methods of fixation may tether the



Fig. 11 Subsequent normal growth of the distal ulna 2 years after injury



Fig. 12 Lateral radiograph of a 20-year-old college hockey player who had a radius shaft fracture at age 15. He complains of ulnar-sided wrist pain and on exam has prominence of the ulnar head, swelling and instability at the DRUJ. Note the extension deformity of the radius and the soft tissue shadow

distal ulna physis (nonabsorbable suture, internal fixation devices, intraosseous wire), in which case they should be removed. There is also a relatively high rate of premature physeal arrest of the distal ulna. Arrest may not be evident for up to 18 months. Treatment of growth arrest depends upon amount of ulna variance and degree of symptoms as reported by the patient.

10 Cross-References

► Distal Third Radius Fractures with an Intact Ulna



Fig. 13 PA radiograph of a 20-year-old college hockey player who had a radius shaft fracture at age 15. He complains of ulnar-sided wrist pain and on exam has prominence of the ulnar head, swelling and instability at the DRUJ. Note the chronic ulna styloid non-union

References and Suggested Reading

- Eberl R, Singer G, Schalamon J, Petnehazy T, Hoellwarth ME (2008) Galeazzi lesions in children and adolescents: treatment and outcome. *Clin Orthop Relat Res* 466:1705–1709
- Landfried MJ, Stenlik M, Susi JG (1991) Variant of Galeazzi fracture-dislocation in children. *J Pediatr Orthop* 11(3):332–335
- Letts M, Rowhani N (1993) Galeazzi-equivalent injuries in children. *J Pediatr Orthop* 13:561–566
- Rettig ME, Raskin KB (2001) Galeazzi fracture-dislocation: a new treatment-oriented classification. *J Hand Surg* 26A:228–235
- Walsh H, McLaren C, Owen R (1987) Galeazzi fractures in children. *J Bone Joint Surg* 69B:730–733

Volar Shear Fractures of the Distal Radius

Meryl Ludwig and Jennifer M. Ty

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Abstract

A 10-year-old right-hand-dominant female sustained a fall onto her left arm and presented with a closed left Salter Harris II fracture of her distal radius with a volar shear component. This fracture pattern is better defined in adult patients and almost always necessitates surgery in the adult population because of the inability to maintain reduction in a closed manner. An attempt at closed reduction was performed in this case; however, it did not achieve satisfactory alignment. Open reduction and pinning of the fracture was performed. Pins were removed in the office at 4 weeks, and at 8 weeks postoperatively, she had full range of motion of her wrist. At 18 months postoperatively, there was no radiographic or clinical signs of a physeal bar or growth arrest.

1 Brief Clinical History

A 10-year-old right-hand-dominant female sustained a fall onto her left wrist. She sustained a Salter Harris II, volar shear fracture of her left distal radius. She denied any numbness or tingling and was neurovascularly intact. Due to the displacement and inability to maintain alignment in a cast, the decision was made to proceed with operative fixation.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1(a, b)

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Fig. 1 (a, b) Original radiographs showing a volar shear distal radius fracture



Fig. 2 (a, b) Postoperative radiographs in cast

3 Preoperative Problem List

1. Salter Harris II fracture
2. Closed versus open reduction
3. Choice of fracture fixation

4 Treatment Strategy

An attempt at closed reduction was made in the operating room; however, fluoroscopic imaging showed continued volar displacement. Due to the instability of this fracture and the shear component, it was felt that the best option would be to perform an open reduction in order to anatomically reduce the volar shear fracture. Open reduction was performed through an anterior distal Henry approach to the forearm. An incision was made over the flexor carpi radialis (FCR) tendon, and through the FCR tendon sheath, the pronator quadratus was elevated and a freer elevator was used to reduce the fracture. The fracture was reduced and held while two 0.062 K-wires were placed from proximal to distal percutaneous outside of the skin. Appropriate reduction was confirmed on fluoroscopic imaging. The pronator quadratus was repaired, then the subcutaneous tissue and skin were closed, and a short arm cast was applied.

5 Basic Principles

1. The distal radial physis contributes to 75% of the growth of the radius; therefore, there is a substantial amount of remodeling (Houshian et al. 2004).
2. Volar displacement usually results from a fall on a flexed wrist (Waters and Bae, 2010).
3. Closed reduction and casting can be attempted for these fractures using a posteriorly directed force with a well molded cast. This can sometimes be challenging due to the shear force at the fracture site and then pinning is indicated.
4. One or two smooth pins should be placed in the metaphysis, avoiding the physis if possible. Pins are removed in the office when sufficient healing is seen on radiographs, usually at 4–6 weeks. Cast immobilization is used in combination with pin fixation until sufficient healing is seen on radiographs (Stutz and Waters 2009).
5. Monitor patients and counsel on possibility of growth arrest of the distal radius. Remodeling potential is greater (and some say complete) in children less than 10 years old. Incomplete remodeling may not have a substantial long-term effect on mobility of wrist or grip strength (Houshian et al. 2004).

6 Images During Treatment

See Figs. 2(a, b) and 3(a, b)

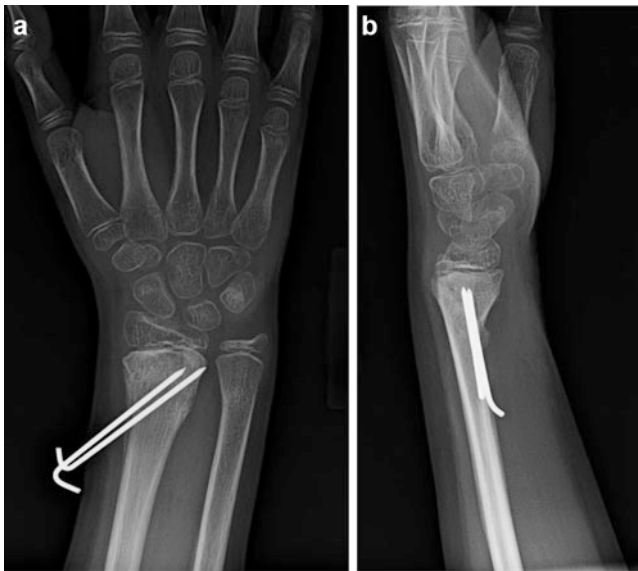


Fig. 3 (a, b) 4 weeks postoperative: alignment maintained

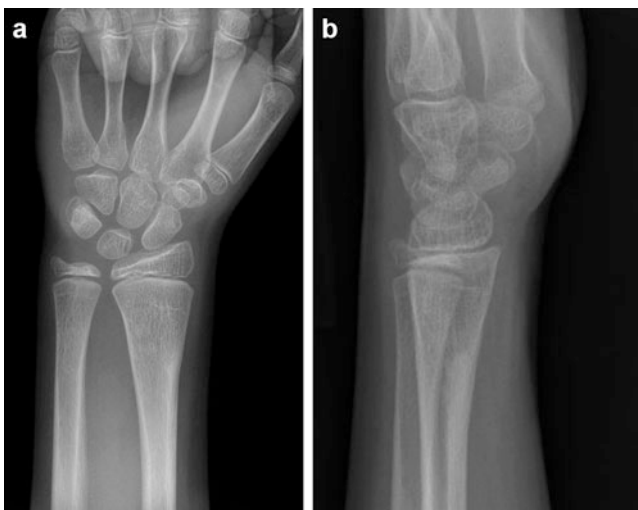


Fig. 4 (a, b) 8 months postoperative: No evidence of bony bar or physeal bridge

7 Technical Pearls

1. A volar shear fracture of the distal radius can be difficult to maintain in a cast due to the shear component of the fracture and the pull of the wrist and finger flexors.
2. When reduction cannot be obtained closed, open reduction should be performed to remove periosteum, interposed muscle, or other blocks to reduction (Waters and Bae, 2010).
3. Fracture pattern anatomy may dictate the best pinning approach, i.e., proximal to distal or distal to proximal.



Fig. 5 (a, b) 18 months postoperative: No evidence of bony bar or physeal bridge

4. It is acceptable to cross the physis with smooth k-wires if necessary.
5. Use of smaller caliber smooth pins and avoiding late manipulation (after 10 days) can minimize the risk of injury to the physis (Stutz and Waters 2009).

8 Outcome Clinical Photos and Radiographs

See Figs. 4(a, b) and 5(a, b)

9 Avoiding and Managing Problems

1. Volar shear fractures of the distal radius are less common in the pediatric population. We believe that the shearing force needs to be taken into account when deciding on treatment and a cast alone may not be able to maintain fracture position.
2. In Salter Harris I and Salter Harris II fractures, the rate of growth arrest is approximately 1–7% and has been linked to repeated, forceful reductions, as well as manipulations 10 days after the injury (Abzug et al. 2014).
3. Percutaneous pin fixation, with closed or open reduction, can be used to maintain fracture alignment (Stutz and Waters 2009).

4. If the fracture is 7–10 days old, no attempts at reduction should be made. Fracture healing and remodeling should be allowed and then an osteotomy can be performed at a later date (Abzug et al. 2014).
5. A shear pattern and displacement can create contact forces between the distal epiphysis and proximal metaphysis and can lead to bony bridging and physeal bar formation.
6. Any bony bar or physeal bridging should be assessed and evaluated appropriately with further imaging.

10 Cross-References

- [Physeal Fracture of the Distal Radius](#)

References and Suggested Reading

- Abzug JM, Little K, Kozin SH (2014) Physeal arrest of the Distal radius. *J Am Acad Orthop Surg* 22(6):381–389
- Houshian S, Holst AK, Larsen MS, Torfing T (2004) Remodeling of salter-Harris type II epiphyseal plate injury of the distal radius. *J Pediatr Orthop* 24:472–476
- Stutz C, Waters PM (2009) Fractures and dislocations of the forearm, wrist, and hand. In: Mencia GA, Swiontkowski MF (eds) *Green's skeletal trauma in children*. Elsevier Saunders, Philadelphia, pp 142–181. Print
- Waters PM, Bae DS (2010) Fractures of the distal radius and ulna. In: Beaty JH, Kasser JR (eds) *Rockwood and Wilkins' fractures in children*. Lippincott Williams and Wilkins, Philadelphia, pp 292–346. Print

Physeal Fracture of the Distal Radius

Christina Ottomeyer and Christopher A. Iobst

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Abstract

A 15-year-old otherwise healthy, right-hand dominant male fell on his outstretched arm sustaining a displaced, left Salter-Harris type II distal radius physeal fracture. The fracture underwent successful closed reduction under conscious sedation in the emergency department with application of a well-molded long-arm cast. He was seen for clinical and radiographic follow-up at 10 days with maintained, acceptable reduction. At his 3-week follow-

up visit, he was converted to a short-arm cast. The fracture went onto union with satisfactory alignment in 6 weeks. At the last follow-up, he had both a good clinical and radiographic outcome, without physeal arrest or residual deformity.

1 Brief Clinical History

A 15-year-old otherwise healthy right-hand dominant male fell onto his outstretched left arm while playing volleyball in gym class. He was brought immediately to the emergency room for evaluation. He complained of pain and deformity to his wrist. He denied numbness/tingling in his hand or fingers. He denied any other associated injuries. On exam, there was a noticeable deformity about the wrist. The skin was intact. He had intact sensation and motor function throughout the median, ulnar, radial, AIN, and PIN nerve distributions. He had palpable radial/ulnar pulses and cap refill was <2 s.

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Fig. 1 Initial AP (a) and lateral (b) injury films showing displaced left distal radius Salter-Harris II fracture with an associated ulnar styloid fracture



2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

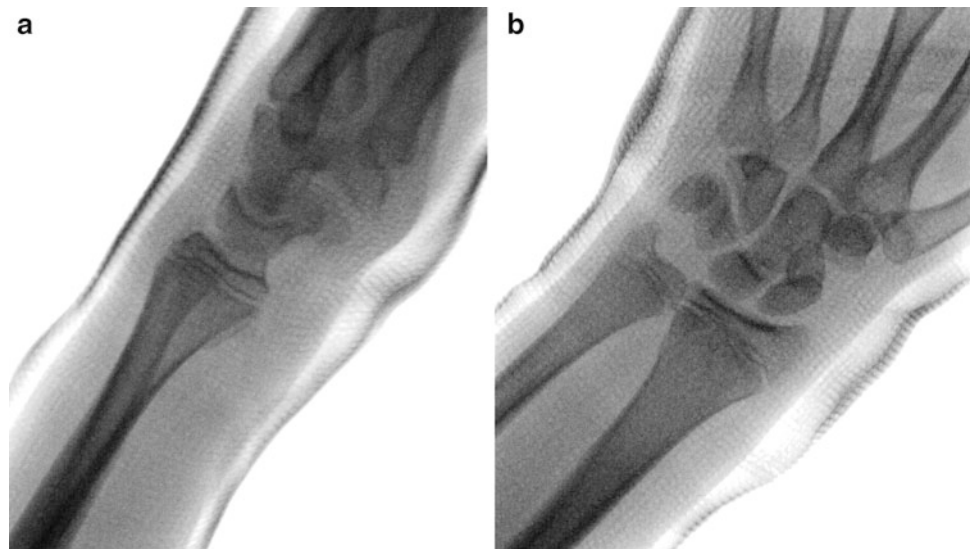
1. Salter-Harris type II distal radius fracture
2. Ulnar styloid fracture
3. Age of patient, consider the number of years of growth remaining (i.e., remodeling potential)
4. Choice of fixation/immobilization

4 Treatment Strategy

Given the acuity of presentation, limited growth potential remaining, and Salter-Harris I/I fracture pattern, the decision was made to treat with closed reduction and

immobilization in the emergency room under conscious sedation. Most authors advocate for a “gentle reduction” or only one attempt at a reduction maneuver to prevent injury to the physis. Therefore, other options to consider during treatment include the possibility of reduction in the operating room under general anesthesia. This method will provide greater muscle relaxation and theoretically create less damage to the physis. While in the operating room, transphyseal fixation with a smooth K-wires can be added to decrease the risk of losing the fracture reduction in the cast. This decision is based on the surgeon’s clinical judgment. Ideally, management of this injury should not require more than one episode of general anesthesia. If the surgeon feels that the reduction is very stable in the cast, then no pinning is necessary. However, if there is any concern about the stability of the fracture reduction, percutaneous pinning of the fracture can be performed. The surgeon must weigh the benefits of having more stable fixation (which implies avoiding any return trip to the operating room) versus the cost of a slightly more invasive procedure.

Fig. 2 AP (b) and lateral (a) immediate postreduction fluoroscopic radiographs show acceptable alignment. Fiberglass cast has been applied



5 Basic Principles

1. The distal radial physis contributes 75% growth of the radius and 40% of entire upper extremity at a growth rate of ~5.25 mm per year.
2. The majority of distal radius physeal fractures are type I or II Salter-Harris fractures, which can be treated with closed reduction and immobilization. Type III and IV fractures of the distal radius are rare but may require open reduction and fixation to anatomically align the joint surface and decrease the risk of physeal arrest. Type V Salter-Harris fractures may have a benign radiographic appearance but can be associated with physeal arrest and therefore should be managed expectantly.
3. Acceptable alignment is controversial. The distal radial physis contributes to 75% of the growth of the radius, and therefore, a substantial amount of remodeling can occur (Houshian et al. 2004). General guidelines are that deformities in the plane of joint motion are more acceptable. Dorsal angulation $<20^\circ$ in patients >10 years old is widely accepted and $<30^\circ$ in children <10 years old.
4. Close follow-up of the fracture for the first 2 weeks is needed to monitor alignment. Radiographs within 7–10 days should be obtained to ensure acceptable alignment has been maintained in the cast. In most cases, the total immobilization time for this injury should be 4–6 weeks.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

1. Closed reduction
 - (a) Consider timing and avoid delayed reduction >1 week after injury, and generally limit to one reduction attempt to reduce the risk of growth arrest. While the rate of growth arrest in distal radius physeal fractures is low (1–7%), multiple reduction attempts are a risk factor for causing a growth arrest (Abzug et al. 2014).
 - (b) The proper reduction technique should: (1) re-create the deformity, (2) utilize longitudinal traction to pull the fracture fragment out to length, (3) apply pressure to push the fracture fragment back into alignment, and (4) manually hold reduction in place until imaging confirms satisfactory alignment and well-molded cast is placed.
 - (c) Alternatively, finger traps can be used to assist with reduction through muscle relaxation and ligamentotaxis.
2. Casting – traditionally consists of a long-arm cast for 6–8 weeks with the possibility of conversion to a short-arm cast after 2–4 weeks depending on the type of fracture and healing response
 - (a) Short-arm vs long-arm cast – well-molded short- or long-arm immobilization has been shown to maintain reduction equally well in several randomized controlled trials of physeal and distal third forearm fractures (Webb et al. 2006; Bohm et al. 2006).
 - (b) The loss of reduction is associated with an increasing cast index (>0.7). The cast index is an indicator of

how well a cast is molded. It is defined as the ratio of sagittal to coronal width from the inside edges of the cast at the fracture site (Chess et al. 1994).

- (c) The principles of good forearm casting technique include appropriate padding, evenly distributed cast material, interosseous molding, supracondylar molding, straight ulnar border, and three-point mold.

3. Operative indications/treatment

- (a) Indications – unstable patterns with loss of reduction in a cast, Salter-Harris I or II fractures in the setting of neurovascular compromise, concern for compartment syndrome with casting, and irreducible fractures.
- (b) Closed reduction with percutaneous pinning.
 - i. Approach by making a small incision to avoid dorsal sensory branch of radial nerve. Perform reduction under fluoroscopy, and maintain reduction with K-wire pinning.
 - ii. Fracture may be held with radial styloid or dorsally placed pins. If instability demands transphyseal fixation, smooth wires are utilized. For intra-articular fractures, pin distal to the physis transversely across epiphysis. Dorsal pins are used to restore volar tilt.
 - iii. Postoperative follow-up for repeat imaging to assess healing/position. Pins are pulled in clinic once callus formation is verified on radiographs.
- (c) Open reduction is indicated with displaced Salter-Harris III and IV fractures of the distal radial physis/epiphysis if they are unable to be closed reduced. The most common blocks to reduction are periosteum and pronator quadratus.

8 Outcome Clinical Photos and Radiographs

See Figs. 3, 4, and 5.

9 Avoiding and Managing Problems

1. Early follow-up after closed reduction is key to allow for safe re-manipulation of the fracture if interval loss of reduction occurs. Consider weekly radiographs to monitor for re-displacement.
2. A physeal crush type V Salter-Harris fracture may be initially missed but is at high risk for physeal arrest and should be followed closely.
3. Distal radius physeal fractures have excellent remodeling potential and clinical forgiveness, with 92% of those over 11 years old achieving complete remodeling (Houshian et al. 2004). However, malunion is the most common complication.
4. Long-term follow-up of distal radius physeal fractures ensures detection of physeal arrest. Compression-type injuries have a higher association with arrest (Lee et al. 1984). Cannata et al. found that a growth arrest up to 1 cm was well tolerated (Cannata et al. 2003). If an arrest occurs, a physeal bar resection may be performed if anatomically possible. Alternatively, ulnar shortening osteotomy, or radial lengthening osteotomy may be necessary to avoid ulnar positive variance and subsequent ulnar-sided wrist pain.
5. Casting thermal injury may occur if: dipping water temperature is >24C (75F), more than eight layers of plaster

Fig. 3 Reduction maintained at 10-day follow-up

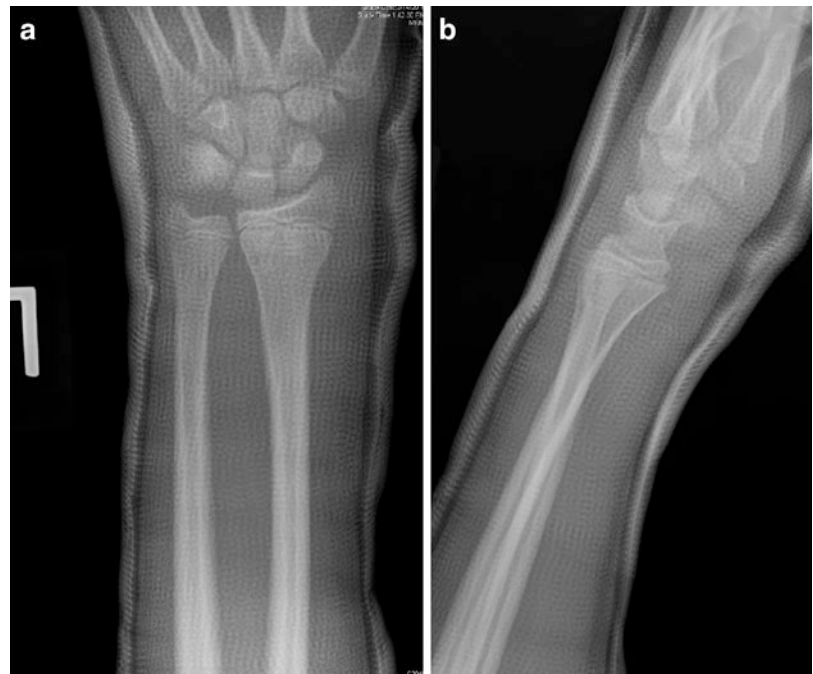
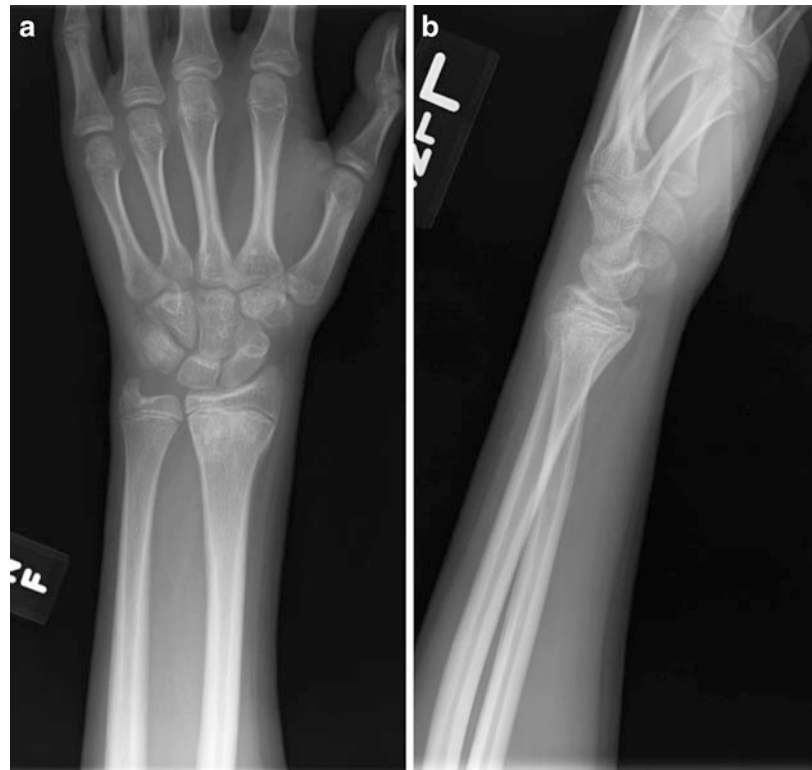


Fig. 4 Radiographs at 3-week follow-up. Alignment is unchanged, and patient was transitioned from a long arm cast to short arm cast for an additional 3 weeks



Fig. 5 Radiographs at 6-week follow-up demonstrating fracture healing and preservation of the physis



are used, fiberglass is overwrapped over plaster, or during cast setting, the arm is placed on a pillow, decreasing the dissipation of heat from the exothermic reaction (Halanski et al. 2007).

6. Neuropathy/neurapraxia – the median nerve is the most commonly affected. Transient neurapraxia must be distinguished from acute carpal tunnel syndrome which is associated with increasing pain and progressive sensory

deficit, followed by recurrent median nerve branch motor weakness. Acute carpal tunnel syndrome requires urgent surgical open nerve decompression if fracture reduction does not reverse the symptoms. In these cases, the fracture should be percutaneously pinned to obviate the need for a subsequent tightly molded cast.

7. Ulnar styloid nonunions are very common and usually asymptomatic. Occasionally, overgrowth can be noted with symptoms of ulnar impingement that responds to excision and TFCC repair.

10 Cross-References

- [Long Arm Cast](#)
- [Management of Late Displacement \(>5 days\) of a Previously Reduced Salter II Distal Radius Fracture](#)
- [Short Arm Cast](#)
- [Volar Shear Fractures of the Distal Radius](#)

References and Suggested Readings

- Abzug JM, Little K, Kozin SH (2014) Physeal arrest of the distal radius. *J Am Acad Orthop* 22:381–389
- Bohm ER, Bubbar V, Yong Hing K, Dzus A (2006) Above and below-the-elbow plaster casts for distal forearm fractures in children. A randomized controlled trial. *J Bone Joint Surg Am* 88(1):1–8
- Cannata G, De Maio F, Mancini F, Ippolito E (2003) Physeal fractures of the distal radius and ulna: long-term prognosis. *J Orthop Trauma* 17(3):172–179
- Chess DG, Hyndman JC, Leahey JL et al (1994) Short arm plaster cast for distal pediatric forearm fractures. *J Pediatr Orthop* 14:211–213
- Halanski MA, Halanski AD, Oza A, Vanderby R, Munoz A, Noonan KJ (2007) Thermal injury with contemporary cast-application techniques and methods to circumvent morbidity. *J Bone Joint Surg Am* 89(11):2369–2377
- Houshian S, Holst AK, Larsen MS, Torfing T (2004) Remodeling of Salter-Harris type II epiphyseal plate injury of the distal radius. *J Pediatr Orthop* 24(5):472–476
- Lee BS, Esterhai JL Jr, Das M (1984) Fracture of the distal radial epiphysis: characteristics and surgical treatment of premature post-traumatic epiphyseal closure. *Clin Orthop Relat Res* 185:90–96
- Webb GR, Galpin RD, Armstrong DG (2006) Comparison of short and long arm plaster casts for displaced fractures in the distal third of the forearm in children. *J Bone Joint Surg Am* 88(1):9–17

Scaphoid Fracture: Dorsal Approach

Christine A. Ho

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Abstract

A 12-year-old healthy female sustained a left scaphoid fracture 4 weeks prior. Radiographs 4 weeks after the injury revealed a left scaphoid waist fracture that is displaced with a scaphoid/stress radiograph. Open reduction fracture resorption leads to a cystic defect. The child was placed in a short arm thumb spica cast for 6 weeks and then transitioned to a removable thumb spica splint. Union was present at 3 months, and the child had full range of motion at that time with no pain.

1 Brief Clinical History

A 12-year-old healthy female suffered a left scaphoid fracture 4 weeks prior. Because there were no deformity and minimal pain, the family did not seek medical attention at the time of injury. Due to persistent wrist pain, a radiograph was performed, revealing a left scaphoid waist fracture, and the child was subsequently referred to an orthopedist. A scaphoid stress radiograph (clenched fist with ulnar deviation) demonstrated gross displacement. The fracture site already had sclerosis and early cystic changes. Options of casting versus surgical treatment were discussed with the family. It was felt that due to the displacement and early sclerosis/cysts, the fracture would heal more reliably with surgical treatment with a headless compression screw. Due to the cystic changes, it was decided that local bone graft from the distal radius would be used. Because there was no humpback deformity and the fracture was at the waist of the scaphoid (proximal to the perforating vessels), a dorsal approach was selected.

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Fig. 1 AP (a) and lateral (b) radiographs of the wrist reveal a minimally displaced scaphoid waist fracture. There is no humpback deformity. However, there already is sclerosis surrounding the fracture site as

well as bony resorption at the fracture site. Scaphoid view (c) demonstrates gapping and displacement at the fracture site. Physes are still open

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Subacute scaphoid waist fracture with cystic and sclerotic changes
2. Approach – dorsal versus volar
3. Need for bone graft
4. Choice of fracture fixation (pins, modular hand screw, headless compression screw)

4 Treatment Strategy

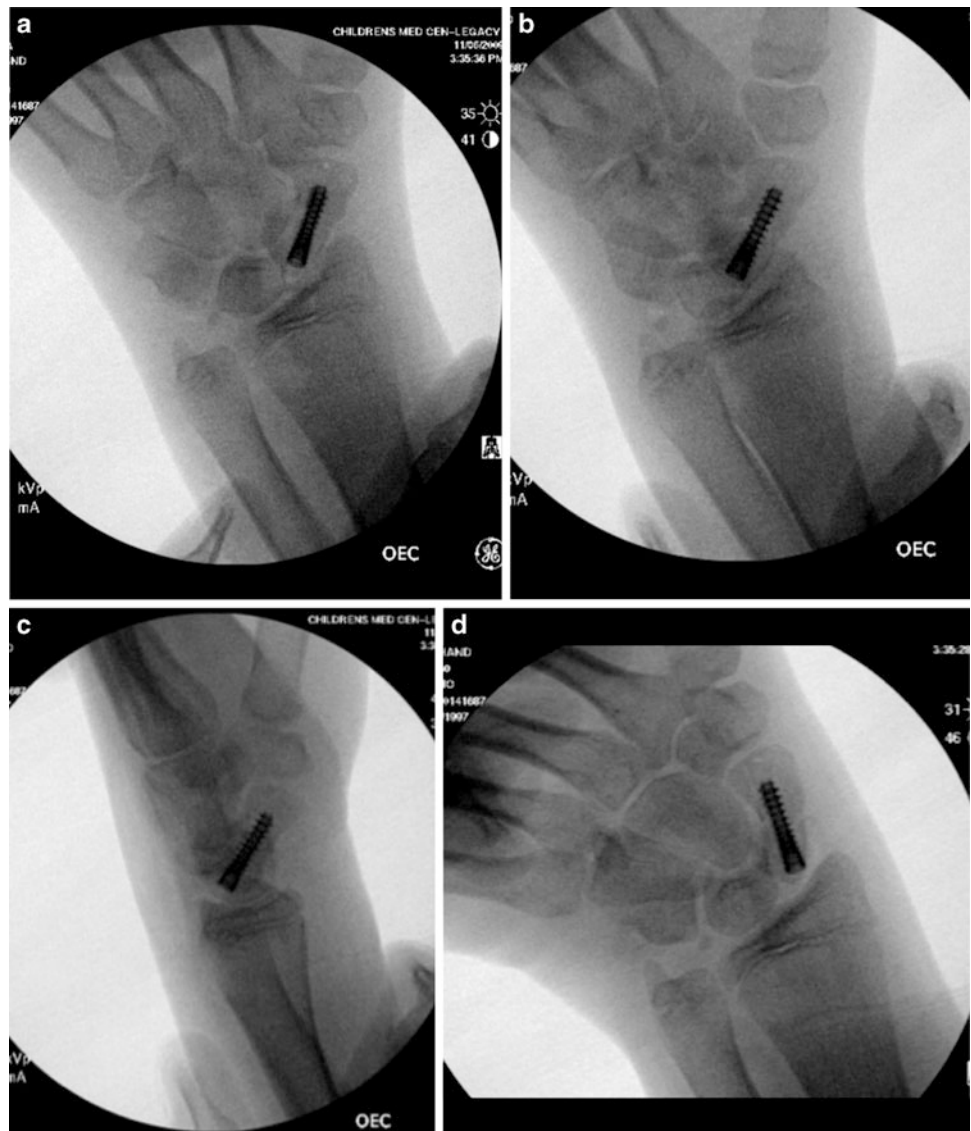
The patient was placed in a thumb spica splint for comfort in the clinic and scheduled for elective outpatient surgery. A dorsal approach was utilized under tourniquet for hemostatic control. A longitudinal incision was made over Lister's tubercle, centered over the radiocarpal joint. The extensor pollicis longus (EPL) was identified proximal to the extensor retinaculum and its sheath released. The EPL was retracted radially and the fourth compartment elevated from the dorsal radius. The radiocarpal joint was incised longitudinally to expose the proximal row. The distal limb of the incision was extended horizontally and radially in an inverted "L" to facilitate exposure. Care was taken to not disturb the dorsal carpal branch of the radial artery which is the blood supply to the

scaphoid. This can be identified as a cuff of perivascular tissue entering the dorsal ridge of the scaphoid, just distal to the scaphoid waist.

As the fracture was relatively acute, the fracture site was easily identified and a microcurette used to debride the fibrous tissue until viable bone was visualized on either side. A 0.045 K-wire was then used to perforate both distal and proximal poles to stimulate healing. One centimeter osteotomes were used to make a cortical window in the distal radius metaphysis, proximal to Lister's tubercle, and cancellous bone graft was harvested. This was packed into the fracture site, and fluoroscopy was used to verify complete filling of the defect. The distal radius cortical window was then carefully levered back into place.

To visualize the entrance for the guidewire (adjacent to the scapholunate ligament), the wrist was flexed to 90° with three blue towels folded under the wrist. The entrance site for the guidewire was verified under fluoroscopy, and with the wrist flexed to 90°, the guidewire for the headless compression screw was inserted in the center-center location along the axis of the scaphoid, just proximal to the distal articular surface. Position was verified under fluoroscopy and a second derotational wire placed across the fracture site, taking care to leave enough from the guidewire to allow screw insertion. The screw length was determined from the depth gauge, and 4 mm was subtracted from this number to account for compression across the fracture site as well as burying the screw under the cartilage. In pediatric patients with thick cartilage, the screw may appear to penetrate the joint on fluoroscopy although it is buried. A cannulated drill was then used to drill the path of the screw. While this step is often not necessarily in adult patients, the author has found that the denser bone of

Fig. 2 Headless compression screw placed along the axis of the scaphoid. AP (a), oblique (b), lateral (c), and scaphoid (d) views confirm fracture reduction, adequate filling of defect with bone graft, and placement of the screw.



pediatric patients makes this step helpful in screw insertion, especially when the larger diameter proximal screw threads enter the scaphoid; failing to overdrill this entry may lead to hoop stresses that propagate fragmentation of the proximal pole. Be prepared to replace the guidewire as the drill is removed; the guidewire often becomes incarcerated with the cannulated drill and is inadvertently removed. The appropriately sized headless compression screw was then placed antegrade across the fracture site, over the guidewire. Placement of the screw (with particular attention to screw length) was then visualized under fluoroscopy, and the guidewire and derotational wire were removed. Final fluoroscopy images were then obtained, as it is nearly impossible to obtain standard images of the scaphoid when the wrist is flexed for insertion of the screw.

The capsule was repaired with absorbable sutures. The sheath of the third compartment may be loosely repaired if

there is not undue restriction on the EPL; if there is, the third compartment should not be repaired. The subcutaneous tissue and skin were then repaired and a short arm thumb spica splint applied. At 1 week postoperatively, the splint was removed, radiographs and the wound were examined, and the patient was placed into a short arm thumb spica cast for 6 weeks.

5 Basic Principles

1. Scaphoid fractures are rare in children of elementary school age and often associate with massive trauma and ipsilateral injuries. Most pediatric scaphoid fractures are seen in adolescents; fracture patterns and incidences are similar to those of adults (Waters and Stewart 2002).

Fig. 3 AP (a), oblique (b), lateral (c), and scaphoid (d) radiographic views at 5 months demonstrate excellent healing, incorporation of bone graft, and no evidence of avascular necrosis. The patient had full range of motion and had returned to all activities at 3 months postoperatively.



- Operative treatment is indicated in pediatric scaphoid fractures that are displaced or unstable.
- Percutaneous fixation is an option in acute fractures.
- Proximal pole scaphoid fractures mandate a dorsal approach. Distal pole scaphoid fractures are best served by a volar approach. Scaphoid waist fractures can be approached either volarly or dorsally, as long as the surgeon takes care to not disturb the entering dorsal vessel.
- Select a screw 4 mm less than the depth measured from the guidewire to allow for compression and countersinking the screw below the articular surface.
- A derotational wire can prevent malrotation of the fracture as the headless compression screw is advanced.
- In pediatric patients, the carpal bones are still incompletely ossified with a large cartilaginous covering; subtracting 4 mm from the measured screw depth prevents the radiographic appearance of intraarticular screw penetration.

6 Images During Treatment

See Fig 2.

7 Technical Pearls

- When utilizing a dorsal approach to the scaphoid, care must be taken to not disturb the dorsal carpal branch of the radial artery as it enters the scaphoid at the dorsal ridge, as this branch is the main blood supply to the scaphoid.
- Flexion and ulnar deviation of the wrist exposes the entry point of the guidewire for the headless compression screw.

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

- Fluoroscopy should be used when distal radius bone graft is harvested to ensure the graft is taken well proximal to the physis to prevent physeal arrest.

2. Overdrilling or using a countersink in the entry site allows entry of the wider-diameter proximal screw threads and can prevent fragmentation of the entry site.
3. Selecting too long a screw length can lead to distraction at the fracture site during compression.

10 Cross-References

► [Short Arm Cast](#)

References and Suggested Readings

- Ahmed I, Ashton F, Tay WK, Porter D (2014) The pediatric fracture of the scaphoid in patients aged 13 years and under: an epidemiological study. *J Pediatr Orthop* 34(2):150–154
- Anz AW, Bushnell BD, Bynum DK, Chloros GD, Wiesler ER (2009) Pediatric scaphoid fractures. *J Am Acad Orthop Surg* 17(2):77–87
- Bae DS, Gholson JJ, Zurakowski D, Waters PM (2016) Functional outcomes after treatment of scaphoid fractures in children and adolescents. *J Pediatr Orthop* 36(1):13–18
- Buijze GA, Doornberg JN, Ham JS, Ring D, Bhandari M, Poolman RW (2010) Surgical compared with conservative treatment for acute nondisplaced or minimally displaced scaphoid fractures: a systematic review and meta-analysis of randomized controlled trials. *J Bone Joint Surg Am* 92(6):1534–1544
- Gholson JJ, Bae DS, Zurakowski D, Waters PM (2011) Scaphoid fractures in children and adolescents: contemporary injury patterns and factors influencing time to union. *J Bone Joint Surg Am* 93(13):1210–1219
- Haisman JM, Rohde RS, Weiland AJ (2006) Acute fractures of the scaphoid. *J Bone Joint Surg Am* 88(12):2750–2758
- Huckstadt T, Klitscher D, Weltzien A, Müller LP, Rommens PM, Schier F (2007) Pediatric fractures of the carpal scaphoid: a retrospective clinical and radiological study. *J Pediatr Orthop* 27(4):447–450
- Vinnars B, Pietreanu M, Bodestedt A, Ekenstam FA, Gerdin B (2008) Nonoperative compared with operative treatment of acute scaphoid fractures. A randomized clinical trial. *J Bone Joint Surg Am* 90(6):1176–1185
- Waters PM, Stewart SL (2002) Surgical treatment of nonunion and avascular necrosis of the proximal part of the scaphoid in adolescents. *J Bone Joint Surg Am* 84:915–920

Scaphoid Nonunion: Volar Approach

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Abstract

A 14 + 8 year old healthy male presented with a right distal pole scaphoid nonunion and DISI (dorsal intercalated segment instability) deformity after an injury 6 months prior. Open reduction and internal fixation with structural autograft to correct the humpback deformity was performed via a volar approach. He was placed in a short arm thumb spica cast for 6 weeks and then transitioned to a removable thumb spica splint when healing was present at the 6 week follow-up. Union was present at 3 months, and the patient had full range of motion, no pain, and was released to football.

1 Brief Clinical History

A 14 + 8 year old healthy male presented to clinic complaining of 6 months of right wrist pain after falling on it during a football game. Family was told he had a “sprain” although no radiographs were performed. He continued to play the rest of the season. Due to pain that persisted after football season was over, the family sought medical treatment. Radiographs revealed a right distal pole scaphoid nonunion with cystic changes as well as a DISI deformity on the lateral view. Because of the chronicity of the fracture and radiographic changes, the option of surgical intervention was discussed with the family. Because of the distal location of the nonunion as well as the humpback deformity, it was decided to treat this nonunion with open reduction and internal fixation with corticocancellous bone graft via a volar approach.

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Fig. 1 Anteroposterior radiograph (a) taken revealed a distal pole scaphoid nonunion with cystic changes although some bridging callus. Given that the fracture shows evidence of some healing, consideration might be given to casting. However, the lateral radiograph (b) reveals a DISI deformity with a scapholunate angle of 85 degrees (normal: 30–60

degrees). The waist and proximal pole do not demonstrate signs of avascular necrosis. Physes are still open. Additional radiographs (oblique, scaphoid views) were not obtained as it was felt the views would not provide additional information to alter the surgical plan

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Nonunion distal pole scaphoid fracture
2. Correction of DISI deformity
3. Approach – dorsal versus volar
4. Need for bone graft
5. Choice of fracture fixation

4 Treatment Strategy

The patient was scheduled for outpatient surgery. A volar approach was utilized under tourniquet for hemostatic control. A standard Russe incision was made over the flexor carpi radialis (FCR) tendon and extending distally along the transition between the glabrous skin over the thenar eminence and the dorsal skin, to the level of the trapezium. The FCR sheath was incised and the tendon retracted ulnarly to protect the median nerve. The floor of the FCR sheath was incised to expose the wrist capsule and ligaments. Proximally, the flexor pollicis longus was retracted ulnarly and

the pronator quadratus incised to expose the volar distal radius for bone graft. The volar branch of the radial artery was retracted radially. The capsule was incised longitudinally, and the radiolunate and radioscapocapitate ligaments divided distally. The scaphotrapezial (ST) joint was identified.

Exposure of the nonunion site was facilitated by wrist extension and ulnar deviation. Fluoroscopy was used to identify the nonunion site, which was covered with cartilage. The nonunion site was debrided with a microcurette until viable cancellous bone was identified. Care was taken to not disrupt the intact dorsal cortex. The wrist was then flexed until the lunate was in a neutral position on the lateral fluoroscopic view, and a 0.062 K wire was then placed antegrade from the distal radius to the lunate, transfixing the lunate in a neutral position. A 0.062 K wire was placed in the distal pole as a joystick. The scaphoid was reduced and the humpback corrected using the joystick, manipulating the distal fragment into supination and extension. The volar defect was measured, and a corticocancellous graft of corresponding size was harvested from the volar distal radius. Additional cancellous bone graft was harvested from the bone graft site. The cancellous bone was packed into the nonunion defect, and the corticocancellous graft carefully tamped into the volar nonunion site to act as structural graft.

Correction of deformity was verified under fluoroscopy, and a guidewire placed in the central axis of the scaphoid,



Fig. 2 Lateral fluoroscopic view (a) demonstrating a radiolunate wire to correct the dorsal angulation of the lunate and proximal scaphoid. Anteroposterior (b) and scaphoid (c) views demonstrate central axis placement of the headless compression screw through the trapezoid.

Lateral fluoroscopic view after the transfixing wire is removed (d) show correction of DISI and humpback deformities. The structural cortical graft is evident volarly

from the trapezium into the ST joint, and across the scaphoid into the distal pole. A second derotational wire was placed, taking care to not interfere with planned screw trajectory. The trapezium entrance was overreamed with a cannulated drill, and the measuring device placed over the guidewire to measure the screw length. 4 mm was subtracted to allow for compression and countersinking. Because of the dense pediatric bone, the distal entry in the scaphoid was drilled with the cannulated drill bit over the guidewire. The appropriately size headless compression screw was then inserted over the guidewire into the scaphoid until desired compression was achieved. Fluoroscopy verified that the threads of the screw were fully across the nonunion site to achieve compression. The wires were

removed, and final fluoroscopy images were taken to verify reduction of the nonunion, complete filling of the nonunion site with bone graft, and placement of the screw. The wound was irrigated and the capsule and ligaments repaired with nonabsorbable suture. The subcutaneous tissue and skin were then repaired, and a short arm thumb spica splint applied.

5 Basic Principles

1. Healing of pediatric scaphoid nonunion with nonoperative treatment, even distal pole nonunions, mimics healing rates in adults.



Fig. 3 Final Anteroposterior (a), oblique (b), scaphoid (c), and lateral (d) radiographs at 4 months demonstrates complete healing with incorporation of the bone graft and correction of the DISI

deformity. There is no evidence of avascular necrosis. The patient had full range of motion, no pain, and had returned to spring football practice 1 month prior

2. DISI deformity should be identified on preoperative images and corrected intraoperatively with structural bone graft.
3. Distal pole scaphoid fractures are best visualized via a volar approach.
4. The volar branch of the radial artery should be identified and protected during the approach.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

1. When correcting DISI deformity, it is helpful to pin the lunate (and therefore the proximal scaphoid if the scapholunate ligament is intact) in a neutral position and then use a K wire to joystick the distal pole into anatomic position.
2. Humpback deformity is most easily corrected from the volar approach.
3. When placing a headless compression screw retrograde from the volar approach, the volar lip of the trapezium can be resected, the trapezium can be displaced dorsally with

- an elevator, or the guidewire can be placed through the trapezium and the trapezium overdrilled.
4. In pediatric patients, the carpal bones are still incompletely unossified with a large cartilaginous covering; subtracting 4 mm from the measured screw depth prevents the radiographic appearance of intraarticular screw penetration.
 5. A derotational wire prevents inadvertent malrotation of the fracture during screw insertion.

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

1. Although the majority of blood supply to the scaphoid is from the dorsal branch of the radial artery, the volar branch should also be protected during the volar approach.
2. Care should be taken to not violate the intact dorsal cortex, which can destabilize the nonunion.

3. Fluoroscopy should be used when distal radius bone graft is harvested to ensure the graft is taken well proximal to the physis to prevent physeal arrest.
4. Central axis entry point is impossible without removing part of the volar trapezium or placing the entry through the trapezium.
5. In pediatric patients with dense bone, overdrilling of the entry site can prevent fragmentation when the larger diameter threads of the headless compression screw enter the scaphoid and can also prevent inadvertent distraction of the nonunion site.

10 Cross-References

► [Scaphoid Fracture: Dorsal Approach](#)

References and Suggested Readings

- Henderson B, Letts M (2003) Operative management of pediatric scaphoid fracture nonunion. *J Pediatr Orthop* 23(3):402–406
- Mintzer CM, Waters PM (1999) Surgical treatment of pediatric scaphoid fracture nonunions. *J Pediatr Orthop* 19(2):236–239

Thumb Metacarpal Base Fracture

Rameez A. Qudsi, Nancy J. Moontasri, and Jennifer M. Ty

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Abstract

A 13-year-old boy presents with an acute sport-related thumb injury. Radiographs demonstrate a minimally displaced intra-articular fracture at the base of the first metacarpal. He was treated nonoperatively with thumb spica cast immobilization for 1 month. At that time, he was noted to be asymptomatic and he was allowed to return to full activities.

A 14-year-old girl also presents with an acute sport-related thumb injury. Radiographs demonstrate an extra-articular fracture at the base of the first metacarpal. She was initially splinted. However, she was noted subsequently to have angulation of her fracture. She underwent closed reduction and percutaneous pinning. The pins were removed after 4 weeks. She returned to full activity at 7 weeks.

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1 Brief Clinical History

1.1 Case 1

A 13-year-old left-hand-dominant boy was hit in the right hand while playing baseball. He continued to play, but the next day noticed worsening pain and swelling and presented to an urgent care clinic where he was noted to have a closed



Fig. 1 (a–c) Oblique, lateral, and anteroposterior radiographs of the right thumb demonstrating a minimally displaced Salter-Harris III fracture at the base of the first metacarpal

injury of the right thumb with no deformity or neurovascular deficits. Radiographs revealed a Salter-Harris III minimally displaced fracture of the first metacarpal base (Fig. 1a–c). He was placed into a thumb spica splint and referred to the orthopedic clinic for management.

1.2 Case 2

A 14-year-old right-hand-dominant girl was kicked on her right thumb while playing football. She was evaluated in the emergency room where examination confirmed a closed injury in a well-perfused thumb with no neurologic deficit. Radiographs demonstrated a moderately displaced extra-articular base of the thumb metacarpal fracture as well as a

non-displaced intra-articular distal phalanx fracture in a patient near skeletal maturity (Fig. 2a–c).

2 Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Problem List

1. Case Closed intra-articular fracture of the base of the first metacarpal
2. Case Closed extra-articular fracture of the base of the first metacarpal



Fig. 2 (a–c) Anteroposterior, oblique, and lateral radiographs of the right hand demonstrating a moderately displaced extra-articular fracture of the first metacarpal

4 Treatment Strategy

The hand is one of the most common sites of injury in children, often due to crush injuries in young children and sport-related trauma in adolescents. The thumb is the second most common digit fractured (after the small finger), and the metacarpals are the second most common bone involved (after the phalanges) (Vadivelu et al. 2006). The physis of the first metacarpal, unlike those of the other rays, is located proximally increasing the importance of proper recognition and treatment of these injuries.

Once a first metacarpal base fracture is identified, further classification can be performed by fracture location, physeal involvement, and articular extension (Kozin 2006). These fractures can be characterized in different ways. They may be extra-physeal at the level of the proximal metaphysis or involve the growth plate. Physeal injuries may be extra-articular Salter-Harris (SH) II fractures with either a medial or lateral metaphyseal fragment or intra-articular SH III or IV fractures. As patients approach skeletal maturity, more adult-type injuries may be seen such as Bennett (partial articular) or Rolando (complete articular) fracture patterns. These fortunately are not frequent in children.

Displacement, angulation, and stability determine treatment recommendations. The thumb carpometacarpal (CMC) joint is saddle-shaped and allows for a large amount of movement in nearly all planes. Extra-physeal base of the first metacarpal fractures are located near the physis, resulting in high remodeling potential in skeletally immature patients

with growth remaining. Many fractures in this area may be treated nonoperatively without long-term deformity or reduced function. In extra-physeal fractures, up to 30° angulation can be acceptable in children with growth remaining or up to 20° in older patients. Fractures displaced beyond 30° in skeletally immature children treated nonoperatively have a 50% rate of failure and subsequent pinning (Jehanno et al. 1999).

Displacement in these fractures often follows a typical pattern of apex-radial angulation with adduction of the distal shaft fragment due to the deforming forces exhibited by muscular attachments. The abductor pollicis longus (APL) inserts into the proximal metacarpal, resulting in abduction of the proximal fragment, while the pull of the adductor pollicis brevis (APB), adductor pollicis (AP), and flexor pollicis brevis (FPB) results in adduction and flexion of the distal fragment.

SH II fractures can typically be casted in situ for minimally displaced injuries, or closed reduced to restore alignment in displaced or angulated fractures. However, SH II fractures with lateral metaphyseal fragments may require operative management for adequate reduction and pinning (Godfrey and Cornwall 2017). Articular fractures, SH III and IV, demand the most critical evaluation as these can be unstable, displaced at the joint, and require operative management. Minimally displaced fractures can be treated with a short arm thumb spica cast and close follow-up every 5–7 days, but displaced patterns are treated with closed versus open reduction and usually pin fixation to maintain reduction.



Fig. 3 Case 1: Follow-up radiographs at 1 week (a, b) and 4 weeks (c–e) after injury demonstrating minimal displacement with nonoperative treatment

In the operating room, closed reduction is usually successful for extra-physeal or SH II fractures with a medial metaphyseal fragment. The reduction maneuver typically consists of longitudinal traction, abduction, extension, and pronation of the thumb with direct pressure on the apex of the deformity. Percutaneous pinning may be performed with a retrograde cross-pin technique, using two radial entry pins or radial and ulnar entry. A short arm thumb spica cast may then be placed for supplemental immobilization and protection of the pins. Radiographs may be checked at 3–4 weeks, and the pins are usually removed in the office at that time.

Open reduction may be required for SH III or IV intra-articular fractures or SH II fractures with lateral metaphyseal

fragment. A radial curvilinear incision at the glabrous-non-glaborous junction at the base of the thumb can provide good exposure for reduction and subsequent pinning. Internal fixation is uncommonly used in the pediatric population.

After cast removal, patients may benefit from a short course of therapy to recover range of motion and strength and usually resume full activity by 4–8 weeks.

4.1 Case 1

As overall alignment appeared acceptable, the patient was placed into a short arm thumb spica cast for nonoperative



Fig. 4 Case 2: Follow-up radiographs at 1 week (a–c) demonstrating metacarpal base fracture displacement and angulation in the typical pattern due to deforming forces. No change in non-displaced distal phalanx fracture

management. The family was counseled about the need for close follow-up and the risks of displacement and physal involvement. He was seen after 1 week for repeat imaging out of cast, examined under fluoroscopy by the orthopedic physician with confirmation of minimal displacement and acceptable articular congruity, and placed into a new short arm thumb spica cast (Fig. 3a, b). He returned for follow-up at 3.5 weeks after initial casting with repeat imaging and examination out of cast. Radiographs demonstrated maintained acceptable articular congruity and no interval displacement of the fracture (Fig. 3c–e). On examination, he had no deformity and had full sensation of the thumb with no tenderness or instability on both passive and active motion. He was instructed to use a thumb spica removable splint for 2 weeks and progress to activities as tolerated.

4.2 Case 2

After initial review and discussion with patient and family regarding mild to moderate displacement, remodeling potential, and risk of progression, the patient was placed into

thumb spica immobilization with instructions for close follow-up. She was seen 1 week later with repeat radiographs demonstrating interval progression of angulation, and at that point, the decision was made for operative management (Fig. 4a–c). The following day she was taken to the operating room for closed reduction and percutaneous pinning with two radial cross-pins (Fig. 5a–c). She was placed into a short arm thumb spica cast.

After 1 week, she returned for follow-up in clinic with no signs of infection or neurovascular deficit. Alignment was maintained on radiographs (Fig. 6a), and she was placed into a new short arm thumb spica cast for 3 more weeks. At that time 4 weeks after surgery, repeat imaging confirmed maintained alignment with evidence of healing across the fracture site (Fig. 6b–d), and pins were removed in the clinic. She was placed into a removable thumb spica splint for protection during daytime activities.

At final follow-up 6 weeks after pinning, she had intact sensation, active motion of the extensor pollicis longus (EPL), flexor pollicis longus (FPL), thumb adduction and palmar abduction and no tenderness or swelling at the

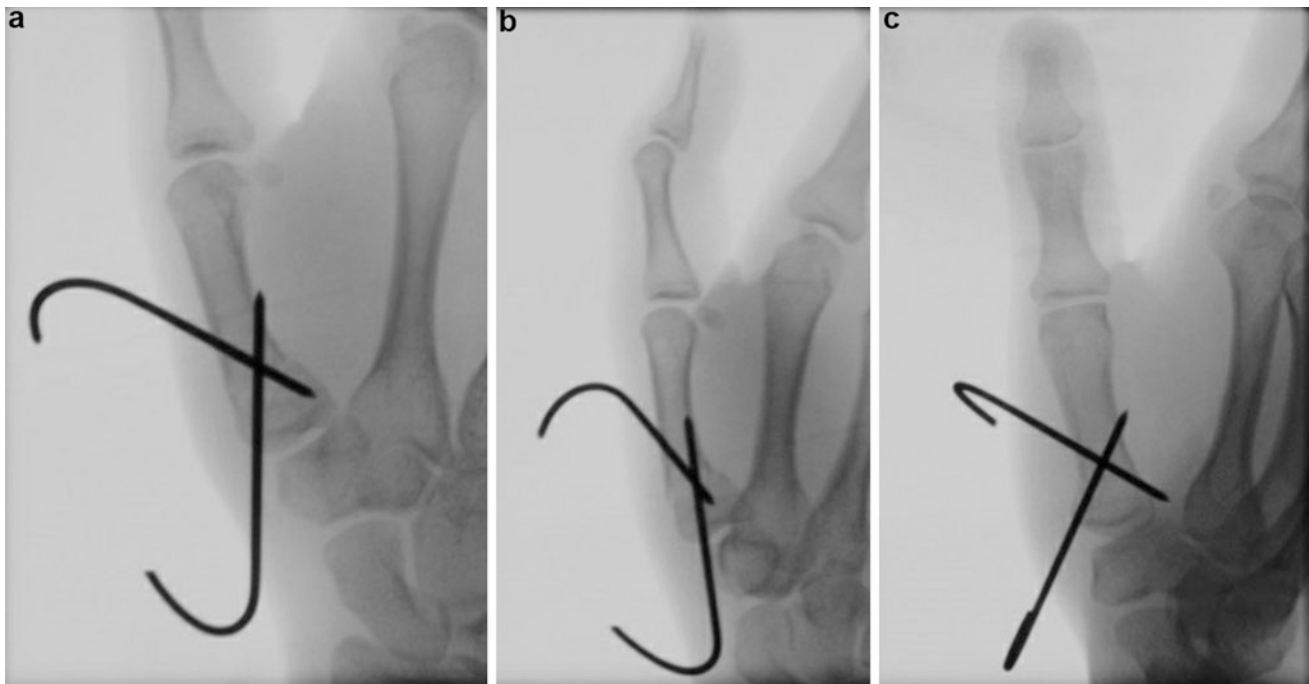


Fig. 5 Case 2: (a–c) Intra-operative fluoroscopic oblique, lateral, and anteroposterior images after closed reduction and cross-pinning of fracture

fracture site. Radiographs confirmed healing of the fracture with good alignment on all views (Fig. 6e–g). She was instructed to discontinue the splint, use a soft foam exercise ball to aid in grip strength, and to resume all activity as tolerated.

5 Basic Principles

- Thumb metacarpal base fractures often occur during sport-related activity by older children.
- Appropriate imaging of the thumb, rather than the hand, is important to assess fracture pattern and displacement.
- Remodeling potential and long-term thumb function are high in children with metacarpal base fractures due to the proximal location of the physis in the metacarpal and the wide range of motion through the thumb CMC saddle joint.
- Extra-physeal fractures with greater than 30° of angulation, SH II fractures with lateral metaphyseal fragment, and SH III and IV fractures displaced more than 1–2 mm typically require operative management for reduction and pin stabilization.
- Closed reduction and percutaneous pinning is the mainstay of operative treatment when indicated with open reduction typically reserved for articular fractures, SH II fractures with lateral metaphyseal fragment, or any situation when closed reduction does not improve alignment into an acceptable range.

6 Images During Treatment

See Figs. 3, 4, 5, and 6.

7 Technical Pearls

1. Imaging: While static plain films can provide the highest resolution imaging, it may be difficult at times to obtain ideal views. Fluoroscopic examination by the orthopedic surgeon may provide the best assessment of the fracture and displacement in these situations.
2. Closed reduction: The reduction maneuver typically consists of longitudinal traction, abduction, extension, and pronation of the thumb with direct pressure on the apex of the deformity.
3. Open treatment: A radial-sided curvilinear incision at the base of the thumb at the glabrous-non-glabrous junction of the skin can provide adequate exposure for reduction. This incision and approach can be extended across the CMC joint if needed – reduction at the joint must be confirmed in displaced intra-articular fractures either by direct visualization or good radiographic imaging.
4. Pinning: Retrograde cross-pinning across the fracture is appropriate for most operative fractures at the base of the thumb. Two pins entering from the radial side or one radial



Fig. 6 Case 3: (a–d) Follow-up radiographs at 1 week after surgery (a) and 4 weeks when pins were pulled (b–d). (e–g) Final radiographs 6 weeks after pinning demonstrating well-healed fracture in good alignment

and one ulnar-sided pin can both be performed as needed based on fracture pattern, but radial-sided pins may be safer in avoiding ulnar-sided volar neurovascular structures.

For unstable fractures near or through the articular surface, with a small proximal fragment, pinning across the CMC joint with a smooth wire may be appropriate to provide adequate fixation.

5. Casting: Typically, these fractures are treated with a short arm thumb spica cast to the tip of the thumb. If the fracture is significantly displaced, it may be difficult to maintain the reduction with cast immobilization, and pin fixation may assist in fracture stabilization. Care must be taken to avoid skin pressure or pinching in the first webspace during cast application.

8 Outcome Clinical Photos and Radiographs

See Fig. 6.

9 Avoiding and Managing Problems

1. Appropriate radiographs of the thumb are needed to fully assess base of the first metacarpal fractures. While two views may be sufficient in some cases (anteroposterior (AP) and lateral), a three-view series with an additional oblique view is common to evaluate thumb metacarpal base fractures.

2. Close follow-up of fractures treated nonoperatively is essential to avoid delayed identification of displacement during treatment. We recommend repeat imaging within 5–7 days of initial reduction and/or casting.
3. Extra-physeal base of the first metacarpal fractures may have significant remodeling potential. In a young child, a “malunited” fracture of this nature may be monitored for remodeling and may not require formal treatment. However, in an older child, the typical flexion and adduction of the distal fragment may result in narrowing of the first webspace and compensatory metacarpal phalangeal joint hyperextension. This can be addressed with a corrective osteotomy.

References and Suggested Readings

- Godfrey J, Cornwall R (2017) Pediatric metacarpal fractures. Instr Course Lect 66:437–445
- Jehanno P, Iselin F, Frajman JM, Penneçot GF, Glicenstein J (1999) Fractures of the base of the first metacarpal in children. Role of K-wire stabilisation. *Chir Main* 18(3):184–190
- Kozin SH (2006) Fractures and dislocations along the pediatric thumb ray. *Hand Clin* 22(1):19–29. Review
- Vadivelu R, Dias JJ, Burke FD, Stanton J (2006) Hand injuries in children: a prospective study. *J Pediatr Orthop* 26(1):29–35

Open Treatment of Metacarpal Shaft Fractures

Joshua A. Gordon and Apurva S. Shah

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Abstract

A 14-year-old male sustained an injury to the right hand while playing basketball. Clinical and radiographic evaluation revealed fractures of the index and long metacarpals in the right hand. A preoperative plan was developed based on the severity of the patient's injury in the context of his overall clinical picture. Surgical treatment using an open reduction and internal fixation approach was deemed optimal. The fractures were fixed using lag screws. The patient's recovery was complete. The only notable post-operative issue was stiffness, but this resolved with occupational therapy (OT). The patient was able to return to normal activity and athletics.

1 Brief Clinical History

A 14-year-old male with a previous history of resolved right brachial plexus palsy was seen after he fell and lost consciousness while playing basketball. During the course of this episode he injured his right hand, which was painful and swollen. There was also marked tenderness to palpation of the dorsum of the hand. Examination of finger flexion was done using the tenodesis effect; with wrist extension there was congruous flexion of the fingers and no rotational deformity. This was assessed by observing the position of fingers and the nail plates when compared to the uninjured fingers and the contralateral hand. The hand and forearm remained soft and the overlying skin was intact. Radiographs of the injured right hand showed a long oblique fracture of the index finger metacarpal shaft and a comminuted long oblique fracture of the long finger metacarpal shaft.

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Fig. 1 A Posteroanterior (PA) radiograph demonstrating a long spiral oblique fracture of the index metacarpal and a comminuted spiral fracture of the long finger metacarpal along the radial aspect. The appropriate series of radiographs to evaluate metacarpal fractures are seen in Figs. 1, 2, and 3, with PA, oblique, and lateral views of the hand. On oblique imaging, metacarpals of the index and long fingers are better viewed with supination, while metacarpals of the ring and small fingers are better viewed with the hand prone. Both the fractured metacarpals are noted to be shortened



Fig. 2 Lateral radiograph demonstrating flexion deformity of the long and index metacarpal fractures

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4.

3 Preoperative Problem List

1. Index finger spiral metacarpal shaft fracture
2. Comminuted long finger spiral metacarpal shaft fracture

4 Treatment Strategy

The treatment strategy for metacarpal fractures is varied and depends on the age of the patient, character of the fracture, number of metacarpal fractures, degree of displacement, concomitant soft tissue injury, and patient expectations.

In this case, the patient is greater than 10 years of age with fused growth plates. As compared to those younger

than 10 years of age in whom 20–30 degrees of angulation in the sagittal plane can be tolerated through a combination of remodeling and tolerance, this patient has only 10–20 degrees of combined tolerance. Slight deformity is well tolerated, and the acceptable upper limit of deformity for the index and long finger metacarpal shaft fractures is 10 degrees of sagittal angulation, this differs for the ring and small finger which tolerate up to 20 degrees of angulation (Lindley and Rulewicz 2006). The guidelines regarding shortening are less clear but minimal shortening is ideal as there is a risk of associated extensor lag. Only minimal metacarpal rotation is acceptable. Border digit involvement and multiple metacarpal fractures are more problematic and therefore serve as additional relative indications for surgical fixation.

In this patient, the significant angulation of 25 degrees of flexion in the index and long fingers, the involvement of both the index and long metacarpals, and the border position of the index metacarpal suggest the need for surgery. The inherent lack of stability indicated by this clinical presentation and the fracture configuration suggest the need for open reduction and stable fixation as opposed to K-wire fixation, which is often appropriate in the case of single metacarpal shaft fractures. Here, based on the spiral fracture pattern, shortening



Fig. 3 Supinated oblique radiograph demonstrating long and index metacarpal fractures. Some degree of metacarpal shortening is evident on this view. Further, the radial-sided comminution appears as a single dominant butterfly fragment on the volar radial aspect of the metacarpal



Fig. 4 Phalangeal line test demonstrating normal alignment despite visualized fractures (as described in Fig. 1; Campbell 1990)

and the need to start early joint mobilization, the choice was made to proceed with lag screw fixation of both metacarpal fractures. It is important to note that in the case of stable fractures amenable to nonoperative treatment casting with the MCPs flexed to approximately 90° and the PIP joint flexed to 20° is an appropriate treatment.

5 Basic Principles

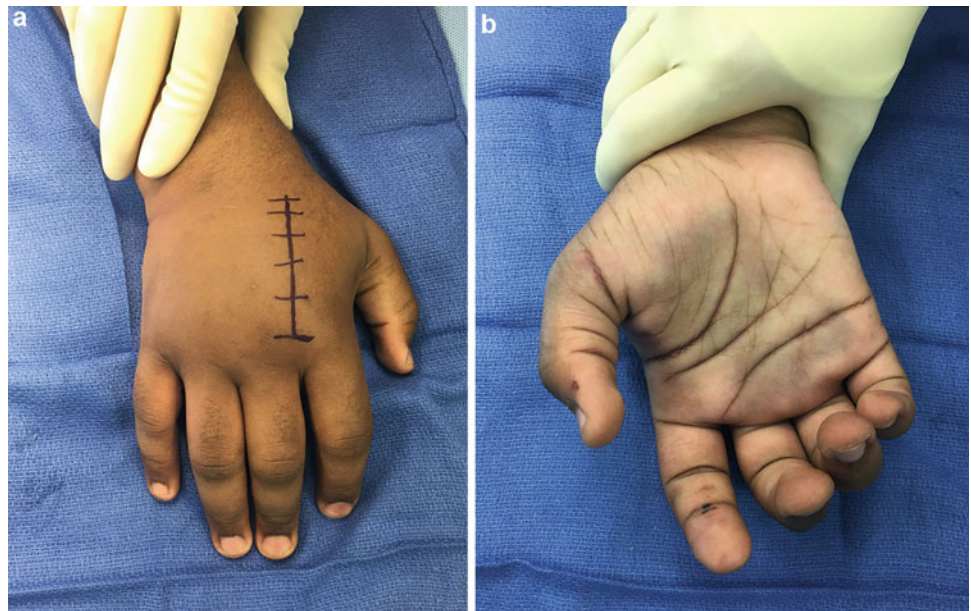
Metacarpal fractures can often be treated with closed reduction and immobilization. In more severe injuries percutaneous pinning or open reduction and fixation may be needed. Principles guiding the treatment decisions hinge on the related anatomy, configuration of the fracture pattern, amount of soft tissue trauma, presence of instability and an assessment of the patient's capacity to regain normal function without complications. Fittingly the typical classification of metacarpal fractures is descriptive, including location, displacement, angulation and rotation of the fracture, involvement of the physis and intra-articular extension (Cassel and Shah 2015). Fractures in older pediatric patients and those that are further from the growth plate have diminished capacity for remodeling, another important consideration



Fig. 5 It demonstrates the appropriate positioning on a hand table with a tourniquet applied to the upper arm. A plastic adhesive drape is placed around the distal end of the tourniquet to avoid prep solution from

collecting beneath the tourniquet; the hand is now ready for preparation and drape placement

Fig. 6 (a) Incisional markings indicate an incision planned between the 2nd and 3rd rays allowing access to both metacarpals through a single incision. Moderate hand swelling is evident. (b) Extensive ecchymosis seen on the palmer side of the hand at the time of surgery



when determining the need for operative intervention. It is important to recognize that the thumb metacarpal physis is located proximally while the finger metacarpal physes are located distally. Stability is also diminished in shaft fractures and in clinical circumstances that destabilize the intermetacarpal ligamentous support, such as border location or multiple metacarpal fractures. Fractures with articular incongruity or with 20% articular surface involvement require reduction and surgical fixation to restore the metacarpophalangeal joint surface (Weinstein and Hanel 2002). Due to limited capacity to remodel in the axial plane, any degree of clinically evident malrotation requires correction.

6 Images During Treatment

See Figs. 5, 6, 7, 8, and 9.

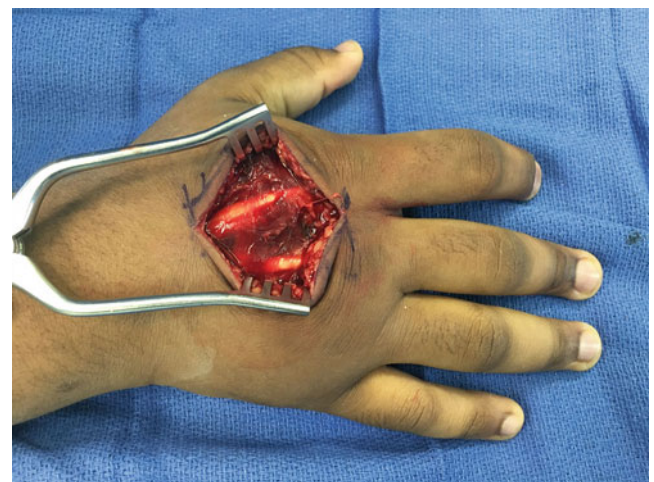


Fig. 7 Exposure of the index and long metacarpal. Dissection proceeded with caution to avoid injury to branches of the superficial radial nerve

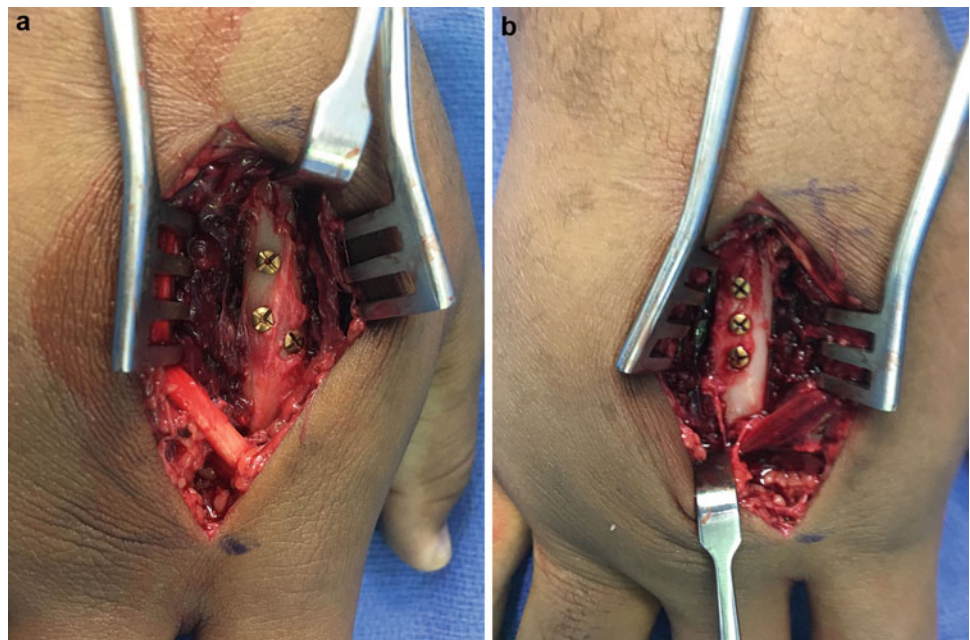
7 Technical Pearls

In young patients general anesthesia may be preferable, while in older children regional anesthesia may be used. For positioning, a hand table is recommended. A mini C-arm facilitates capture of fluoroscopic X-rays with minimal radiation scatter. Repeat of the examination to assess the alignment using the tenodesis effect, palpation of the compartments to ensure they are adequately soft, and re-examination of the tissues to avoid missing fight bites and open fractures should be undertaken. To access



Fig. 8 Reduction maneuver with manipulation of fragments using a freer while a Landonne Oblique/Spiral Metacarpal Fracture Small Bone Clamp was applied. This clamp permits excellent fracture compression and stabilization without excessive periosteal stripping

Fig. 9 Placement of 2.0 mm lag screws perpendicular to fracture plane. (a) Three screws placed in the index followed by three screws placed in the (b) long metacarpal



metacarpal fractures, a linear incision between the involved finger rays can be used and the soft tissue can be mobilized from a single incision to reach multiple metacarpals. The incision should be adequate to allow for manipulation of the fragments at the proximal and distal ends of the fracture. In the case of lag screw placement, it is important that exposure allows for provisional fixation with a Kirschner wire (K-wire) while still leaving room for the definitive fixation. The incision can be carried subcutaneously but always with care to avoid injury to the superficial radial nerve on the radial side and the dorsal sensory branches of the ulnar nerve on the ulnar side. The soft tissue windows require adequate mobilization to allow for subperiosteal dissection through separate windows for each metacarpal. Fixation should build back to the dominant fragment; if a butterfly fragment is present, this should be fixed first, which will simplify reduction. Reduction may also be facilitated by using a dental pick or freer elevator to help adjust bone fragments prior to application of a reduction forceps or other reduction tools. In this case a freer and Landonne Oblique/Spiral Metacarpal Fracture Small Bone Clamp were used. Provisional K-wire fixation to maintain bone position prior to placement of the definitive hardware fixation is often very helpful. In this case, no plate was required as adequate stability was achieved with lag screw fixation, which was mediated by the fracture pattern and bone interference associated with a spiral fracture. Transverse and short oblique fractures are usually more unstable and better treated with plate fixation. Prior to closure, the position of the digits, especially any rotational abnormality, should be re-evaluated. We also advocate for closure of the



Fig. 10 Postoperative PA radiograph demonstrating near anatomic restoration of coronal plane alignment



Fig. 11 Postoperative lateral radiograph demonstrating near anatomic restoration of sagittal plane alignment



Fig. 12 Postoperative oblique radiograph confirming adequate reduction and lag screw fixation

fascia with an absorbable suture in order to enhance post-operative tendon gliding and reduce the risk of adhesion formation.

8 Outcome Clinical Photos and Radiographs

See Figs. 10, 11, and 12.

9 Avoiding and Managing Problems

Two major pitfalls can be avoided with careful evaluation: compartment syndrome and the presence of open fractures. In the case of an obtunded patient with severe swelling and soft tissue injury, the use of a needle manometry may allow for accurate assessment of compartment pressures. A careful examination and detailed exam should reveal open wounds or the need for compartment release at the time of surgery. As the most frequently encountered complication is post-operative stiffness, in the case of open reduction and internal fixation with a stable construct early rehabilitation should be undertaken. In cases with greater comminution, incomplete

restoration of axial alignment can lead to cross-over with attempted flexion. This complication is avoidable with examination of digital cascade, and if necessary, comparison to the contralateral side. Lastly it should be noted that after healing, fractures with residual flexion deformity may be at increased risk for refracture, particularly for transverse diaphyseal fractures.

References and Suggested Reading

- Abzug JM. The pediatric upper extremity. Springer. <http://www.springer.com/us/book/9781461485131>. Accessed 25 Sept 2016
- Campbell RM (1990) Operative treatment of fractures and dislocations of the hand and wrist region in children. *Orthop Clin North Am* 21(2):217–243
- Cassel and Shah AS (2015) Metacarpal Fractures in the Pediatric Upper Extremity (Editors Abzug JA, Kozin SH, Zlotolow DA), Springer, New York, NY, p981–1004
- Lindley SG, Rulewicz G (2006) Hand fractures and dislocations in the developing skeleton. *Hand Clin* 22(3):253–268. <https://doi.org/10.1016/j.hcl.2006.05.002>
- Weinstein LP, Hanel DP (2002) Metacarpal fractures. *J Am Soc Surg Hand* 2(4):168–180. <https://doi.org/10.1053/jssh.2002.36788>

Pediatric Metacarpal Neck Fractures

Krister Freese

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Abstract

This chapter will cover the treatment of metacarpal neck fractures. Metacarpal neck fractures are among the most common pediatric hand fracture. Treatment is frequently conservative. However, in some scenarios, surgical intervention is preferred. Rotational and angular deformities may have a detrimental effect on hand function if left untreated. When present, closed reduction and immobilization or surgical fixation may be indicated. In the following text, we will discuss the successful management of a metacarpal neck fracture.

1 Brief Clinical History

The patient is a 9-year-old male who injured his right index finger while playing baseball. A baseball hit the distal aspect of the index metacarpal while the patient had a closed fist. The patient had immediate onset of pain and subsequent swelling and ecchymosis about the distal aspect of the index metacarpal. He was seen at an outside hospital where radiographs were obtained and he was splinted in situ. Upon presentation to the hand clinic, he had tenderness over his index metacarpal neck and pain with range of motion. The index finger had no appreciable rotational or angular deformity when compared to the contralateral hand. However, his metacarpal head was prominent in his palm.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

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Fig. 1 PA of the right hand demonstrates an index metacarpal neck fracture

3 Preoperative Problem List

Index finger metacarpal neck fracture with significant apex dorsal angulation.

4 Treatment Strategy

Given the fracture location, patient age, and significant angulation of the fracture at presentation, we were concerned that fracture remodeling would not be sufficient to correct the alignment to within acceptable tolerances. The index finger does not tolerate residual apex dorsal angulation as well as more ulnar fingers. A successful closed reduction was achieved and the patient was placed in a well-molded cast for 3 weeks. He was subsequently splinted for comfort and during high-risk activities for an additional 3 weeks. During this time, the patient began hand range of motion exercises. He returned to clinic 6 weeks postinjury with full motion at the metacarpal phalangeal joint. At this time he was released to full activity.

5 Basic Principles

Metacarpal fractures are the most common hand fractures in children. Of metacarpal fracture, the fracture occurs at the metadiaphyseal junction in 27.5% of cases (Vadivelu



Fig. 2 Lateral radiograph of the right hand demonstrating approximately 50° of apex dorsal angulation



Fig. 3 Clinical photograph demonstrating “long” short arm cast

et al. 2006). Metacarpal neck fractures are often treated satisfactorily by nonoperative means. These fractures typically demonstrate apex dorsal angulation. They are more susceptible to rotational and angular deformity than



Fig. 4 Posterior anterior view of the right hand demonstrating a healing index metacarpal neck fracture with abundant callous formation



Fig. 5 Lateral view of the right hand demonstrating well aligned index metacarpal neck fracture with improved apex dorsal angulation

diaphyseal and metacarpal base fractures. In general, the amount of fracture angulation tolerated decreases from the radial side of the hand to the ulnar side of the hand. The ring and small finger carpometacarpal joints allow for greater

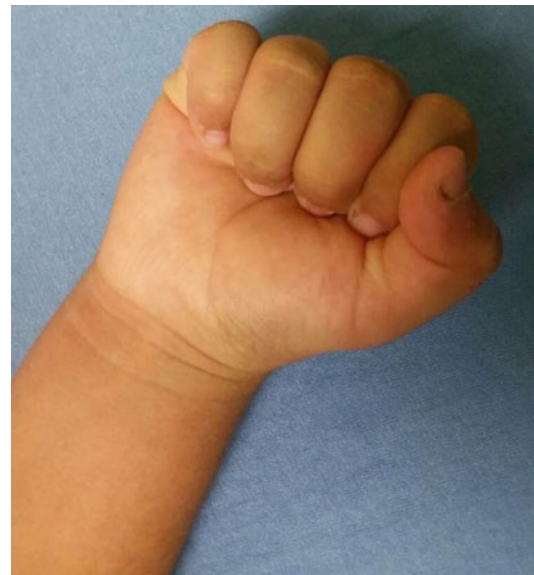


Fig. 6 Full range of motion and no rotational deformity evident on day of cast removal

motion than the index and long finger carpometacarpal joints. The ring finger and small finger carpometacarpal joints are able to compensate for residual angulation. When rotational deformity, angular deformity, or fracture angulation is greater than acceptable tolerances, a closed reduction or surgical intervention is warranted. In skeletally mature patients 10–20° of angulation can be tolerated in the index and long fingers. As much as 60° of angulation can be tolerated in the ring and small fingers. Fractures in the skeletally immature have varying amounts of remodeling potential depending on the patient age, fracture location, and fracture plane. Fracture angulation in the plane of joint motion has more remodeling potential than rotational deformities which have a negligible ability to remodel. In children less than 10 years old, 20–30° of remodeling can be expected. Children older than 10 years are capable of remodeling 10–20° of angulation (Kozin and Waters 2010).

6 Images During Treatment

See Fig. 3.

7 Technical Pearls

Achieving and holding an acceptable closed reduction is paramount to avoiding surgical intervention. Successful closed reduction requires successful analgesia frequently



Fig. 7 No angular deformity noted at conclusion of immobilization

achieved with a digital block. The most common reduction technique is the Jahss maneuver. This involves flexion of the involved finger at the metacarpal phalangeal joint and a dorsally directed force transmitted through the flexed finger. Counter pressure over the fracture site may aid in reduction. Successful immobilization can be achieved in a number of ways. Traditionally an ulnar or radial gutter cast has been used for immobilization. Other options include a “long” short arm cast leaving the interphalangeal joints free or a hand based orthosis (Davison et al. 2016). In the older patient, it is imperative to immobilize the hand in the intrinsic plus position, metacarpal phalangeal joint flexion between 70° and 90° with interphalangeal joint extension. This will

prevent difficulty with metacarpal phalangeal joint stiffness postimmobilization.

8 Outcome Clinical Photos and Radiographs

See Figs. 4, 5, 6 and 7.

9 Avoiding and Managing Problems

Problems with the management of metacarpal neck fractures are relatively uncommon. In some cases, surgical management may be preferred over nonoperative management despite adequate radiographic alignment. Patients who require a strong grip or grasp large cylindrical objects (i.e., racquets, tools, etc.) are sometimes bothered by a prominent metacarpal head in the palm. Other potential problems include cast complications and loss of fracture reduction. Both can be avoided with a technically well applied and appropriately molded cast.

References and Suggested Reading

- Davison PG, Boudreau N et al (2016) Forearm-based ulnar gutter versus hand-based thermoplastic splint for pediatric metacarpal neck fractures: a blinded, randomized trial. *Plast Reconstr Surg* 137(3): 908–916
- Kozin SH, Waters PM (2010) Fractures and dislocations of the hand and carpus in children. In: Beaty JH, Kasser JR (eds) *Rockwood & Wilkins' fractures in children*, 7th edn. Lippincott Williams & Wilkins, Philadelphia, pp 225–291
- Vadivelu R et al (2006) Hand injuries in children: a prospective study. *J Pediatr Orthop* 26(1):29–35

Metacarpophalangeal and Interphalangeal Joint Dislocation

Felicity G. L. Fishman

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Abstract

A 15-year-old male sustained an index finger dorsal fracture dislocation of his metacarpophalangeal (MCP) joint. Multiple closed reduction attempts were made in the emergency room but were ultimately unsuccessful. A simple dislocation can become irreducible if multiple attempts at closed reduction are performed via straight traction. The patient was then transferred to a pediatric hospital for further care. Due to the complex nature of this injury, the patient was brought to the operating room. An irreducible dorsal dislocation can be approached volarly or dorsally depending on surgeon preference and concurrent injuries. The dorsal fracture fragment necessitated a dorsal approach for the open reduction and fixation, which also served to avoid the volar neurovascular bundle in the approach to the MCP joint. The dislocated joint was

reduced after releasing the volar plate, which was interposed. The metacarpal head fracture was then stabilized with two 1.3 mm screws. The patient was briefly splinted postoperatively, and early range of motion exercises were initiated within 2 weeks of the injury. The patient regained functional motion within a few weeks of his injury and the fracture healed uneventfully.

1 Brief Clinical History

A 15-year-old right-hand dominant male sustained a right index finger metacarpophalangeal (MCP) joint dislocation with a metacarpal head fracture while playing football. He was seen outside a hospital emergency department where multiple attempted closed reductions were unsuccessful. He was transferred for further care and brought to the operating room for open reduction of his index finger MCP joint and fixation of his metacarpal head fracture with 1.3 mm screws.

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2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Dorsal dislocation of index finger metacarpophalangeal joint
2. Concurrent metacarpal head fracture
3. Choice of approach for open reduction – dorsal versus volar
4. Choice of fixation for fracture fragment – screws versus k wire

4 Treatment Strategy

Closed reduction of metacarpophalangeal joint and interphalangeal joint dislocations may be attempted with local analgesia but may require sedation in younger children. Typically, the wrist is flexed to take tension off of the flexor tendons and then the middle phalanx (PIP dislocation) or proximal phalanx (MCP dislocation) is translated onto the proximal phalanx and metacarpal, respectively, while gentle longitudinal traction is pulled if necessary. In this patient, multiple attempts at closed reduction of the index finger MCP fracture dislocation were made without success. The operative approach to the digit can be dorsal or volar depending on the surgeon's preference and

concomitant injuries. The dorsal metacarpal head fracture necessitated the dorsal approach to the index finger in this case.

5 Basic Principles

1. Complex dislocations typically require open reduction.
2. Volar approach to a dorsal MCP joint dislocation provides direct access to the structures most commonly blocking reduction (transverse metacarpal ligament, flexor tendon, volar plate). The digital nerves are in close proximity to the volar incision utilized in this approach.
3. Dorsal approach for a dorsal MCP joint dislocation allows for incision of the volar plate to allow for reduction of the MCP dislocation without proximity to the digital nerves.
4. Concomitant injuries, such as fractures, should be treated simultaneously with stable fixation to allow for early motion.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

1. Not all MCP joint or interphalangeal (IP) joint dislocations require an open reduction.
2. Closed reduction should consist of wrist flexion to take tension off the flexor tendons, finger flexion, gentle pressure directed in the direction opposite of the dislocation.



Fig. 1 Radiographs of the right hand (PA, oblique, and lateral view) demonstrating a dislocated index finger metacarpophalangeal joint with a second metacarpal head fracture



Fig. 2 Intraoperative fluoroscopic images of the right index finger demonstrate fixation of the second metacarpal head with 1.3 mm screws and reduction of the metacarpophalangeal joint dislocation

Fig. 3 PA (a) and oblique (b) radiographs of right hand approximately 2 weeks status post open reduction and fixation of the second metacarpal head fracture and reduction of index finger MCP dislocation

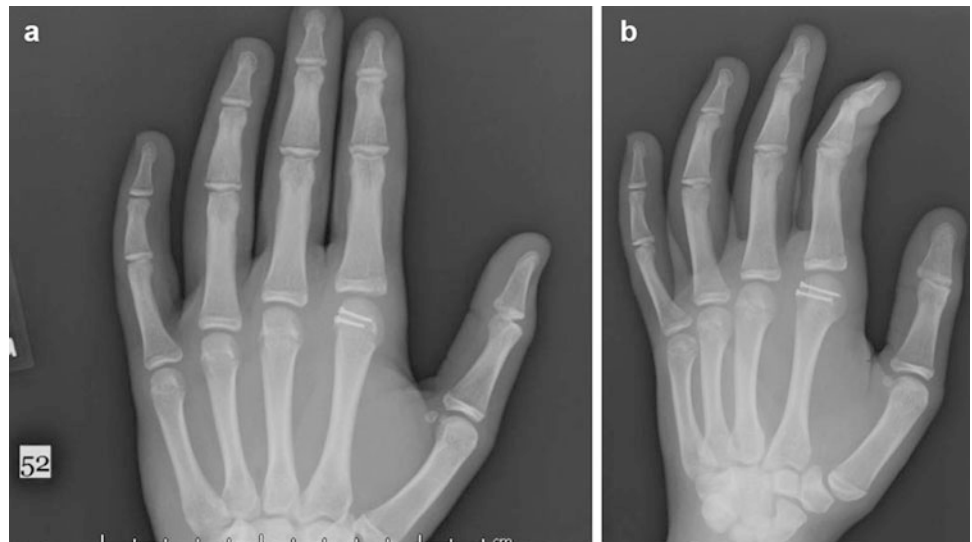
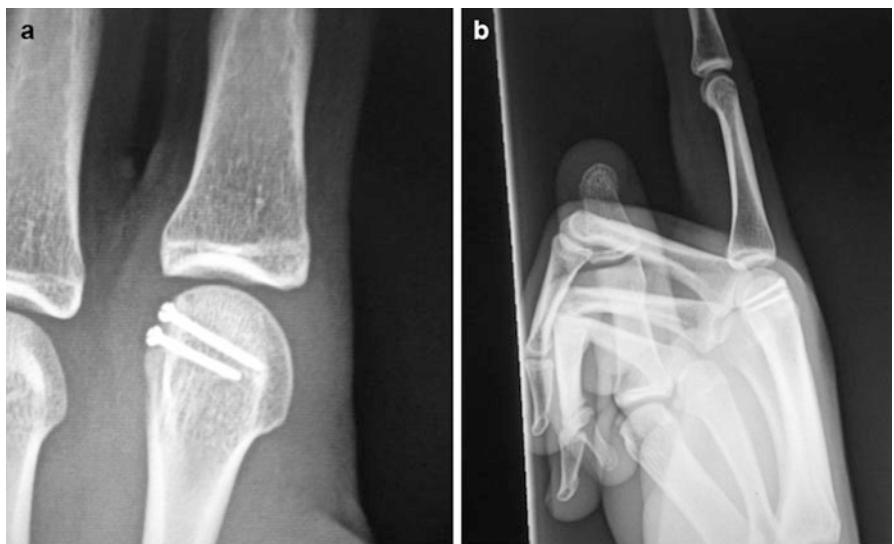


Fig. 4 Oblique (a) and lateral (b) radiographs of right hand approximately 5 months status post open reduction of MCP joint dislocation and fixation of metacarpal head fracture



Do not pull straight traction as this can turn a reducible MCP or IP dislocation into an irreducible dislocation.

3. Advantages of the dorsal approach to the dislocated MCP include visualization of the volar plate and incision without risk to digital nerves.
4. Advantages of the volar approach to the dislocated MCP joint include direct visualization of structures typically involved in a dorsal MCP dislocation and direct visualization of the digital nerves.

8 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

9 Avoiding and Managing Problems

1. Do not pull straight traction attempt during closed reduction of MCP or IP dislocation.
2. Volar approach – incision through skin only as neurovascular bundle may be draped over dislocated metacarpal or phalanx and located very superficially.

3. Reductions may be unstable following reduction and should be taken through a range of motion.
4. Early range of motion following stable closed or open reduction to prevent stiffness.
5. Premature physeal arrest is a potential complication following a IP or MCP joint dislocation in a skeletally immature patient.

10 Cross-References

- [Intra-articular Phalangeal Fractures](#)
- [Phalangeal Shaft Fractures](#)
- [Short Arm Cast](#)

References and Suggested Readings

- Calfee RP, Sommerkamp TG (2009) Fracture-dislocation about the finger joints. *J Hand Surg Am* 34A:1140–1147
- Kozin SH, Waters PM (2006) Fractures and dislocations of the hand and carpus in children. In: Beaty JH, Kasser JR (eds) *Rockwood and Wilkins' fractures in children*, 6th edn. Lippincott Williams & Wilkins, Philadelphia, pp 257–336

Extra-Octave Fractures

Nancy J. Moontasri and Jennifer M. Ty

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Abstract

A 9-year-old female presents with an “extra-octave” fracture – a closed left small finger fracture of the proximal phalanx. The fracture is immediately adjacent to the physis with apex radial and volar displacement. At her initial orthopedic evaluation, she undergoes a reduction maneuver consisting of flexion and adduction under a digital nerve block. She is subsequently placed into an intrinsic plus short arm cast. The fracture heals uneventfully and immobilization is discontinued at 3 weeks.

1 Brief Clinical History

A 9-year-old right-hand dominant female sustains an abduction and extension force to her left small finger while blocking a football pass resulting in finger pain and deformity. She is initially seen by her primary care physician who buddy tapes the ring and small fingers, and she is referred to orthopedics.

On her initial evaluation, she is noted to have an obvious abduction and extension deformity of the left small finger. The fracture site is tender to palpation. Her skin is intact, and she is noted to have normal sensation to light touch in her radial and ulnar digital nerve distribution.

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Fig. 1 Anteroposterior radiography of hand showing fracture of the proximal phalanx of the small finger. There is an apex radial, apex volar deformity. Note that the fracture is juxta-physal



Fig. 2 Oblique radiography of hand showing fracture of the proximal phalanx of the small finger. There is an apex radial, apex volar deformity. Note that the fracture is juxta-physal

2 Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Problem List

1. Juxta-physal proximal phalanx fracture
2. Fracture reduction and immobilization

There has been some controversy about the true nature of these fractures. These fractures have frequently been described in the literature as Salter-Harris II fractures of the proximal phalanx (Leclercq and Korn 2000). However, as Al-Qattan and others have noted, this fracture is better described as juxta-physal as careful examination of the radiographs often shows a small triangular metaphyseal fragment with the fracture line continuing through the metaphysis 1–2 mm from the growth plate (Al-Qattan 2002). Most commonly, this fracture involves the small finger which is extended and ulnarly deviated. This is often described as an “extra-octave” fracture, referring to the

increased ability to span piano keys with an abduction deformity of the small finger.

4 Treatment Strategy

At the patient’s initial presentation, we discussed fracture management with the family and recommended a closed reduction maneuver to be performed under digital block anesthesia. The family consented to this, and this was performed in the office.

A digital block was administered at the level of the metacarpal neck. Ropivacaine 0.2% was chosen for its long duration of action as this offered post-procedural analgesia. Lidocaine 0.5% could also be used. For a border digit such as the pinky finger, the author’s preferred method is to introduce a 1.5 in. 27 gauge needle from the ulnar border of the hand into the volar subcutaneous tissues at the metacarpal neck level. By performing the digital block at the metacarpal neck level, this ensures that the fracture site is included in the zone of anesthesia. Depending on the weight and size of the child, 2–4 cc of local anesthetic can be administered in this fashion



Fig. 3 Lateral radiography of hand showing fracture of the proximal phalanx of the small finger. There is an apex radial, apex volar deformity. Note that the fracture is juxta-physal

on both sides of the digit to block the radial and ulnar digital nerves. An additional 1 cc of local anesthetic can be injected as a subcutaneous wheal to cover the ulnar border of the hand. Finally an additional 1 cc of local anesthetic can be injected as a subcutaneous wheal over the dorsum at the metacarpal head to address the dorsal sensory nerves. Care should be taken to ensure that the total dose of anesthetic does not exceed the maximum safe anesthetic dosage by weight.

The “pencil technique” is commonly recommended for reduction of this fracture. This involves placing a pencil in the webspace to act as a fulcrum for reduction. However, given the anatomy of the webspace, this technique places the fulcrum distal to the apex of the fracture.

The author’s preferred method is to flex the metacarpophalangeal (MCP) joint and adduct the finger. This allows the MCP collateral ligaments to tighten and stabilize the proximal fragment. During the actual reduction, the small finger can be flexed and adducted “under” the ring finger. The ulnar periosteal sleeve remains intact and overcorrection is unlikely. The pinky can then be provisionally buddy taped to

the ring finger. We recommend a “U” of tape beginning at the dorsum of the ring finger, continuing dorsally then ulnarly over the pinky and concluding at the volar aspect of the ring finger. This ensures that swelling will not create any vascular compromise (as might occur with circumferential buddy taping.) The hand can be examined at this point both clinically and radiographically to confirm appropriate reduction and alignment.

The author recommends a short arm cast to include all four fingers in an intrinsic plus position to maintain full adduction of all fingers for 3 weeks. A two finger (ring/small) ulnar gutter cast or splint requires abduction of the middle and ring fingers, and there is a risk of loss of reduction of the adduction position of the fracture. The ring finger becomes abducted to the small finger, instead of the desired adduction of the small finger to the ring finger. This is minimized with a three-finger (middle/ring/small) ulnar gutter cast and eliminated with an intrinsic plus cast with all four fingers in an adducted position.

5 Basic Principles

1. The small finger is the most frequently injured digit in children (Cornwall and Ricchetti 2006, Al-Qattan 2002).
2. The “extra-octave” fracture pattern describes the abducted and ulnarly deviated position of the small finger (Al-Qattan et al. 2008). This is thought to describe the ability to reach another key while piano playing due to the increased finger span.
3. For the reduction, flex and adduct the small finger at the MCP joint, buddy tape using a U-shape leaving the radial side open, and place into a four-finger intrinsic plus cast.
4. Most pediatric hand fractures heal with excellent functional outcomes in 2–3 weeks (Mahabir et al. 2001).

6 Images During Treatment

See Figs. 4 and 5.

7 Technical Pearls

1. Ensure the digital block will include the zone of injury by performing the block at the level of the metacarpal neck.
2. Closed reduction should be performed with the small finger MCP flexed and adducted. This has the advantage of addressing both the typical abduction and extension fracture deformity. Although often recommended, the “pencil technique” places the fulcrum distal to the apex of the fracture.



Fig. 4 Reduction of fracture



Fig. 5 Reduction of fracture

3. Reduction should be maintained by buddy taping the ring and small fingers and placement into a four-finger intrinsic plus cast. Buddy taping the fingers in a “U” and leaving the radial aspect open prevents circumferential constriction. As the main deformity is abduction of the small finger, a four-



Fig. 6 AP image at 3 weeks

finger cast in the intrinsic plus position allows for the fingers to be maintained in a maximally adducted state, whereas an ulnar gutter splint or cast allows abduction. If an ulnar gutter splint or cast is chosen, we would recommend a three-finger (middle/ring/small) ulnar gutter splint or cast to minimize small finger abduction.

4. Cast immobilization can generally be discontinued at 3 weeks.

8 Outcome Clinical Photos and Radiographs

See Fig. 6, 7, and 8.

9 Avoiding and Managing Problems

1. “Digital” blocks can be placed too distally to provide proper anesthesia. The local anesthetic should be injected at the level of the metacarpal neck.



Fig. 7 Oblique image at 3 weeks



Fig. 8 Lateral image at 3 weeks

2. Closed reduction via the “pencil technique” places the fulcrum too distally. Instead, we recommend flexing the MCP joint. The MCP ligaments are placed under tension and stabilize the proximal fragment. The distal fracture fragment can then be flexed and adducted to reduce the fracture. As the ulnar periosteum remains intact, it is uncommon to overreduce the fracture – the small finger can be adducted and flexed under the ring finger during the reduction maneuver.
3. A typical ring/small finger ulnar gutter cast or splint can displace the fracture, as the cast or splint requires abduction of the middle and ring fingers. Instead of adducting the small finger to the ring finger to maintain the fracture alignment, the ring finger may be abducted to the pinky, and the fracture may be allowed to displace. We prefer placement into a four-finger intrinsic plus cast to maintain full adduction of the fingers to avoid this problem.
4. Residual extension through the fracture will create a “pseudo-claw” deformity (apparent hyperextension at the metacarpophalangeal joint and flexion of the interphalangeal joint).
5. It is not well described how much residual angulation or deformity is acceptable. This likely depends upon the age of the child as younger children have more remodeling potential. Typically fracture remodeling is expected to be more likely to resolve with deformity in the plane of joint movement. As the MCP joint does have some adduction-abduction in addition to flexion-extension, it is possible that residual apex radial-volar deformity may correct to some degree with continued growth. The author will often evaluate whether the child can be coaxed to adduct the small finger. If the small finger can be adducted to the ring finger, alignment may be acceptable even if there is a small residual abduction deformity. The degree of extension should be assessed to avoid a “pseudo-claw” deformity.
6. There have been reports of extremely unstable fractures requiring Kirschner wire fixation to maintain reduction as well as irreducible fractures due to soft tissue interposition.
7. Although the pinky finger is most commonly injured and the typical deformity is apex radial and apex volar, all fingers can have a juxta-physeal fracture of the proximal phalanx, and the deformity can be radial or ulnar.

10 Cross-References

► [Phalangeal Shaft Fractures](#)

References and Suggested Readings

- | | |
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| <p>Al-Qattan MM (2002) Juxta-epiphyseal fractures of the base of the proximal phalanx of the fingers in children and adolescents. <i>J Hand Surg Br</i> 27(1):24–30</p> | <p>Al-Qattan MM, Al-zahrani K, Al-boukai AA (2008) The relative incidence of fractures at the base of the proximal phalanx of the fingers in children. <i>J Hand Surg Eur Vol</i> 33(4):465–468</p> <p>Cornwall R, Ricchetti ET (2006) Pediatric phalanx fractures: unique challenges and pitfalls. <i>Clin Orthop Relat Res</i> 445:146–156</p> <p>Leclercq C, Korn W (2000) Articular fractures of the fingers in children. <i>Hand Clin</i> 16(4):523–534, vii. Review</p> <p>Mahabir RC, Kazemi AR, Cannon WG, Courtemanche DJ (2001) Pediatric hand fractures: a review. <i>Pediatr Emerg Care</i> 17(3):153–156</p> <p>Nellans KW, Chung KC (2013) Pediatric hand fractures. <i>Hand Clin</i> 29(4):569–578</p> |
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Phalangeal Shaft Fractures

Kevin J. Little

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Abstract

Children use their hands to explore and interact with their surroundings and consequently frequently injure their hands. As such they frequently sustain fractures of the phalanges, which are the most common hand injuries seen in children. The border digits – the small finger and thumb – are the most frequently fractured in children. Many infants and toddlers injure their hands at home, but the incidence of sports-related hand injuries increases until a peak at age 12. Oftentimes, subtle fractures can be missed initially, as they are stable and do not hurt significantly when contact is avoided. Phalangeal shaft and neck fractures commonly occur in young patients from sports-related activity or can be seen in crush injuries to the digit

(Abzug et al. 2016). The injury can be mild enough that patients may not seek care for several days following the injury. Most patients present with edema and ecchymosis centered over the involved bone, most frequently the proximal phalanx. Range of motion may be limited due to pain, edema, or fracture displacement. Fractures through the shaft of the phalanx are more often unstable and may require operative intervention to control alignment and prevent displacement. Malrotation or scissoring is common and will not remodel and must be identified and treated appropriately (Fig. 1). Almost all phalangeal shaft fractures that require operative intervention can be treated closed with percutaneous K-wire fixation, and open reduction and internal fixation is typically only required for open fractures or those with soft tissue interposition.

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1 Brief Clinical History

A 12-year-old female sustained an injury to her dominant right ring finger while playing basketball. She was initially seen at an urgent care facility and splinted after radiographs



Fig. 1 Clinical photograph of a 12-year-old girl demonstrating a fracture of the index finger with significant bruising and obvious clinical malrotation deformity

Fig. 2 Anteroposterior (a) and lateral (b) radiographs of a 12-year-old girl with a displaced and angulated metadiaphyseal fracture of the proximal phalanx of the right ring finger



demonstrated a proximal phalanx fracture (Figs. 1 and 2). The patient was evaluated in the hand clinic, and she was noted to have a closed injury with moderate bruising and edema. She had limited digital motion, but clinically obvious malrotation was noted on examination. She was scheduled for elective closed reduction and percutaneous pinning 5 days later.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

- Displaced, angulated unstable phalangeal metadiaphyseal fracture.
- Fracture location in metadiaphysis prevents simple pin placement from traditional retrograde approach.
- Pins left exposed for easy removal in clinic.
- Postoperative immobilization in a cast or splint.

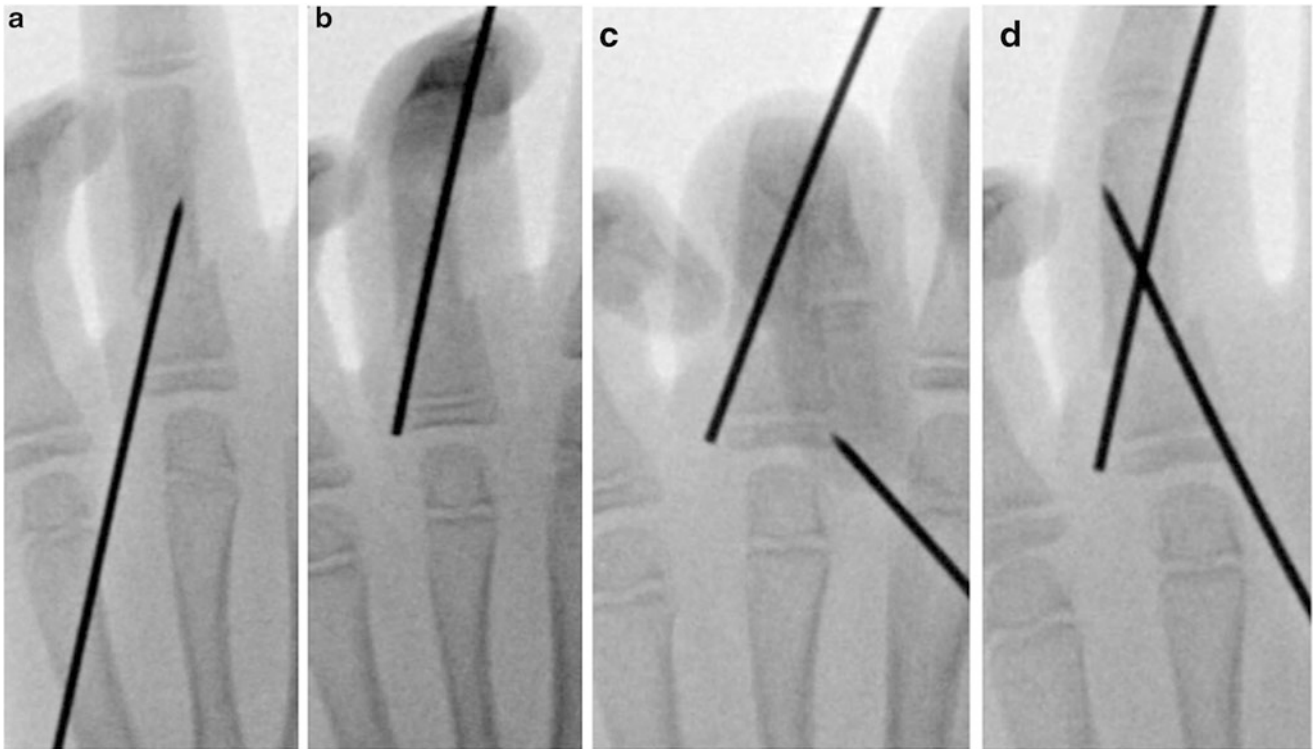


Fig. 3 AP images demonstrating the technique for fixation of this difficult metadiaphyseal fracture. (a) Starting at the radial epiphysis, the 0.045" K-wire is inserted across the fracture and correct alignment and rotation is reassessed. (b) The K-wire is advanced through the distal

ulnar cortex and then pulled out until the end of the pin is just outside the epiphysis. (c) The K-wire is placed at the correct starting point along the ulnar epiphysis. (d). The K-wire is advanced to the distal radial cortex and alignment and rotation are rechecked

Fig. 4 (a) AP and (b) lateral fluoroscopic images demonstrating final fracture fixation with the pins bent and cut short outside the skin

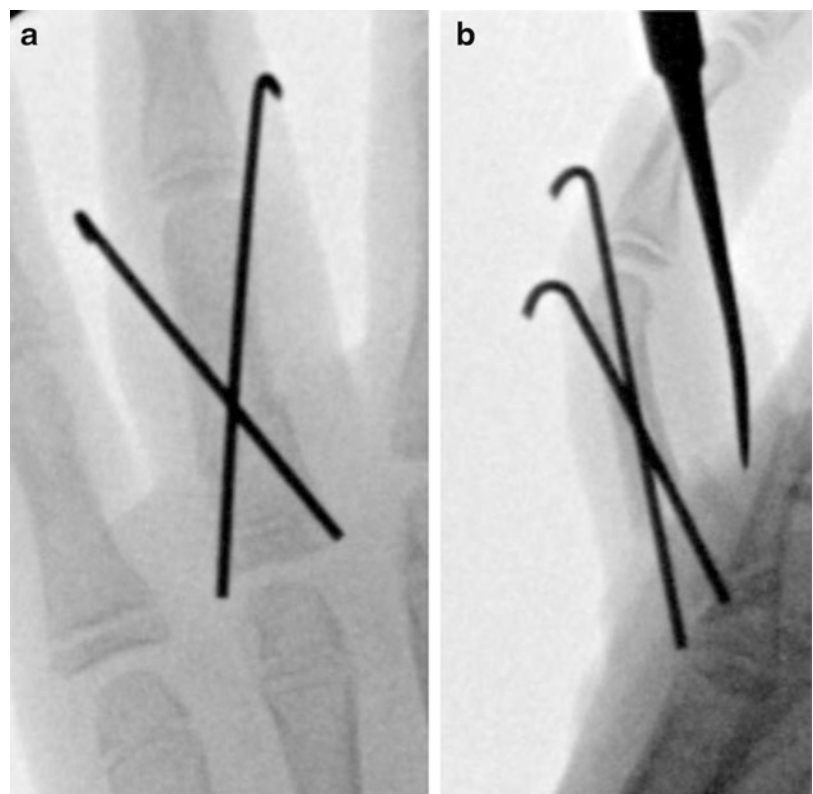
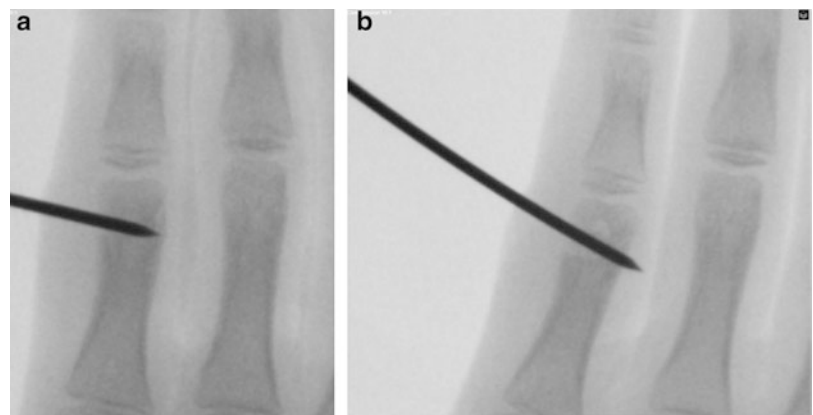


Fig. 5 (a) AP and (b) lateral radiographs demonstrating fracture healing and stable fixation. The pins were removed in clinic and she began ROM exercises. She recovered full motion at 6 weeks postoperatively without any need for occupational therapy



Fig. 6 AP fluoroscopic images demonstrating an osteoclas technique to facilitate reduction. (a) The percutaneous K-wire is inserted across the fracture site to where the tip is resting on the far cortex and then (b) the fracture site is levered open to hold reduction



4 Treatment Strategy

The goal of surgical treatment is to reduce the fracture such that alignment of the finger is normal in the sagittal, coronal, and rotational planes. Reduction is accomplished using MCP flexion to stabilize the proximal phalanx base and by manipulation of the distal fragment. Once anatomic

alignment was achieved, 2 crossed K-wires were placed to stabilize the fracture. In this patient, retrograde pinning attempts were not able to appropriately stabilize the fracture. Antegrade crossed pinning was performed starting at the radial base of the phalanx. The first wire was placed to provisionally fix the fracture (Fig. 3a, b), followed by the second wire from the ulnar side of the epiphysis (Fig. 3b). The pins are bent and cut short prior to casting

(Fig. 4). Casts are well tolerated in children and protect the pins from inadvertent removal. The cast was removed 4 weeks postoperatively, and the pins were removed after radiographs confirmed sufficient fracture healing (Fig. 5). ROM exercises were begun and formal OT was not necessary to regain full function at 6 weeks.

5 Basic Principles

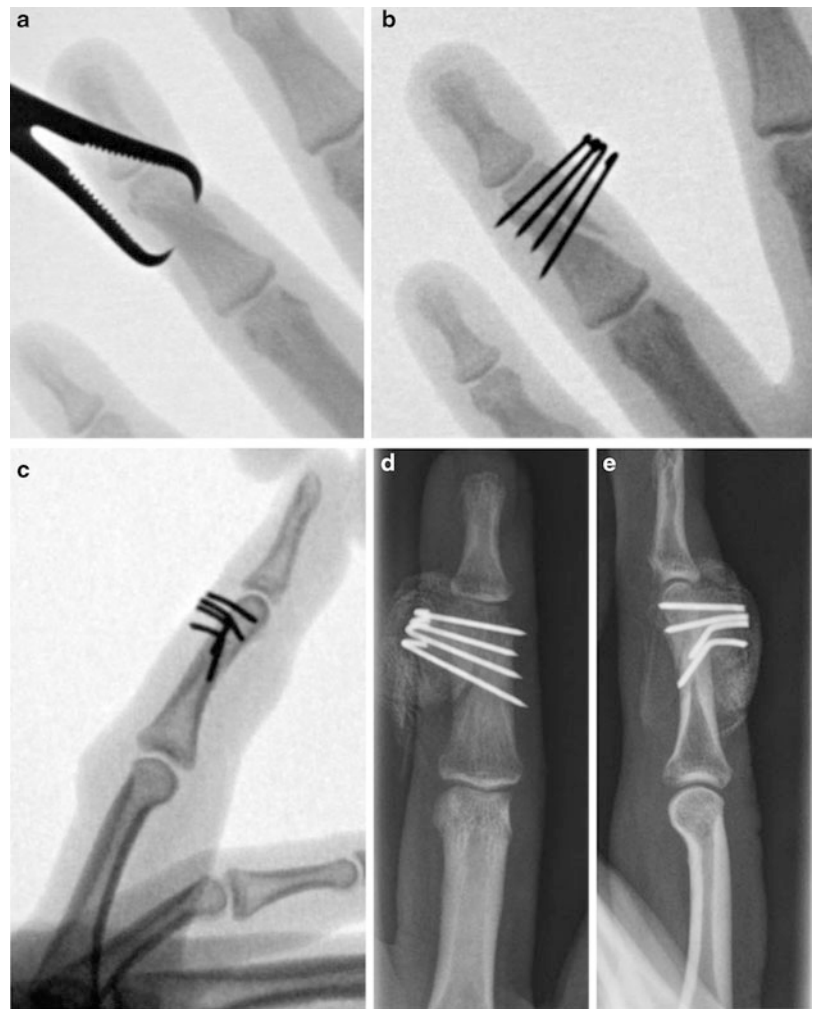
Static splinting or casting can be used for nondisplaced, incomplete phalangeal shaft fractures without the need for follow-up radiographs to confirm clinical healing,

which is best demonstrated with a clinical examination showing full motion and no tenderness to palpation of the affected digit. Remodeling can be expected to occur in the plane of motion in children under age 10. For the proximal phalanx, there is motion in the sagittal plane (flexion/extension) and the coronal plane (abduction/adduction), while in the middle and distal phalanx, there is motion only in the sagittal plane. Stable non-displaced fractures such as metaphyseal buckle fractures or Salter-Harris II physeal fractures do not require weekly alignment checks. Malrotated fractures that require reduction are typically stable when immobilized with buddy taping and a cotton cast. Fracture reduction in a nascent malunion can be augmented with an

Fig. 7 AP (a) and lateral (b) radiographic images of a 12-year-old girl with a completely displaced Salter-Harris II fracture of the ring finger proximal phalanx. The epiphysis is shown (*arrow*) with complete displacement from the metaphysis (*). Open reduction and pin fixation (c and d) was required via a dorsal approach to reduce and stabilize her fracture due to extensor tendon entrapment in the fracture site



Fig. 8 Fluoroscopic images demonstrating a tenaculum-assisted percutaneous reduction (a) and divergent pinning (b, c) used to fix the phalangeal shaft fracture in a 16-year-old girl. AP (d) and lateral (e) radiographs 5 weeks postoperatively demonstrating good healing and no change in alignment. The pins were pulled and she recovered full motion at 6 weeks postoperatively without any need for occupational therapy



osteoclasts technique (Fig. 6) using a percutaneous Kirschner wire (Waters et al. 2004). Two or more Kirschner wires are used to establish stable fixation of the distal fragment to the proximal fragment. Typically, this is done with divergent pinning for oblique fracture patterns and crossed pinning for transverse fractures and phalangeal neck fractures. Open reduction with internal fixation (ORIF) is seldom necessary, but is often required in cases of complete displacement where soft tissues may be interposed preventing reduction (Fig. 7). Early ROM exercises should be promoted with stable fixation via ORIF.

6 Images During Treatment

See Figs. 3, 4, 5, 6, and 7.

7 Technical Pearls

For closed treatment in nondisplaced phalangeal fractures, a careful assessment for angular deformity and malrotation must be performed prior to initiating closed treatment. Stable buckle or Salter-Harris II fractures can be safely treated with buddy tape, a removable splint, or cast. For unstable fractures requiring reduction, placing the MCP joint in flexion stabilizes the collateral ligaments, which allows for manipulation of the phalangeal shaft or neck into anatomic alignment. Percutaneous reduction is preferred as it limits the soft tissue dissection that can compromise vascularity to the phalangeal head. A percutaneous tenaculum clamp may be used to facilitate anatomic reduction in oblique phalangeal shaft fractures (Fig. 8a). K-wires are most commonly placed retrograde across the fracture in either

a cross-pinning or divergent pinning technique (Fig. 8b, c, d, and e). Retrograde pinning longitudinally (similar to flexible nailing of a long bone fracture) down the phalangeal shaft can also be performed in cases

where fracture reduction is difficult to hold. K-wires are bent and cut short and then covered in a cast. The wires are typically kept in place for 4 weeks to ensure appropriate healing and are easily removed in the office.



Fig. 9 AP (a) and lateral (b) radiographs 9 months postoperatively following CRPP. The fracture has fully healed and remodeled back to near anatomic alignment

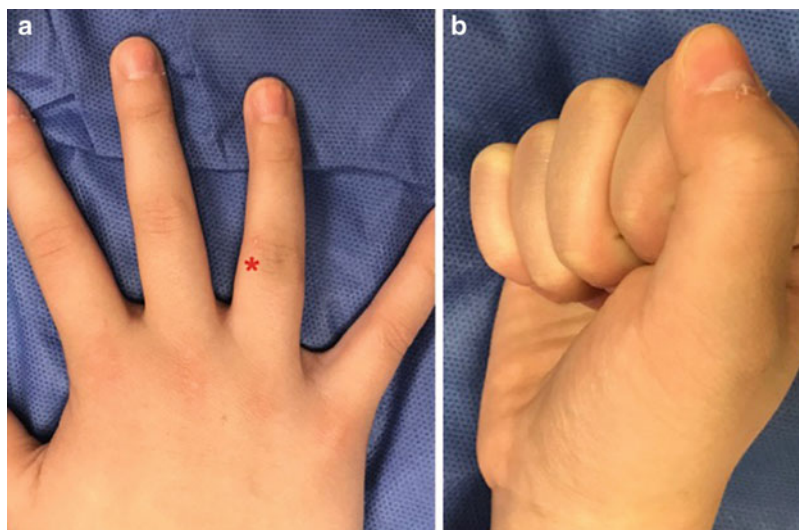
8 Outcome Clinical Photos and Radiographs

See Figs. 8, 9, and 10.

9 Avoiding and Managing Problems

Nearly all phalangeal shaft and neck fractures treated conservatively will regain normal range of motion so long as alignment is maintained within the parameters for clinical remodeling. The most common complication following phalangeal shaft and neck fracture operative treatment is digital stiffness. Most patients can regain functional motion on their own and should be allowed several weeks of home exercises prior to initiating formal occupational therapy. Stiffness is more common in patients with open injuries and concomitant tendon lacerations. As such, formal OT is beneficial as early as possible during the healing phase. Phalangeal fracture malunions frequently lead to loss of motion of the adjacent joint. This can remodel over several years and motion can improve (Puckett et al. 2012), but this should not be relied upon in cases of incipient malunion.

Fig. 10 Clinical photographs taken 9 months postoperatively demonstrate excellent clinical alignment of the finger with full active extension (a) and flexion (b). The pin sites (*) have healed well and are barely visible



Avascular necrosis has been noted in patients with open injuries or following open reduction, which should be avoided. Pin tract infections are rare in phalangeal fractures (Abzug).

10 Cross-References

- [Extra-Octave Fractures](#)
- [Intra-articular Phalangeal Fractures](#)
- [Phalangeal Neck Fractures](#)

References and Suggested Readings

Abzug JM, Dua K, Bauer AS, Cornwall R, Wyrick TO (2016) Pediatric phalanx fractures. *J Am Acad Orthop Surg* 24(11): e174–e183

Matson JL, Cornwall R (2014) A stepwise algorithm for surgical treatment of type II displaced pediatric phalangeal neck fractures. *J Hand Surg [Am]* 39(3):467–473

Nellans KW, Chung KC (2013) Pediatric hand fractures. *Hand Clin* 29(4):569–578

Puckett BN, Gaston RG, Peljovich AE, Lourie GM, Floyd WE (2012) Remodeling potential of phalangeal distal condylar malunions in children. *J Hand Surg [Am]* 37(1):34–41

Waters PM, Taylor BA, Kuo AY (2004) Percutaneous reduction of incipient malunion of phalangeal neck fractures in children. *J Hand Surg [Am]* 29A(4):707–711

Phalangeal Neck Fractures

Julie Balch Samora

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Abstract

Phalangeal neck fractures are principally a pediatric problem and are often missed, which can lead to poor functional outcomes. Synonyms include *subcapital*, *subcondylar*, and *supracondylar phalanx fractures*. These fractures occur at the distal end of the proximal or middle phalanx, with the border digits most often affected. Radiographs must include at a minimum anteroposterior and lateral views, with the displacement more apparent on the lateral image. Phalangeal neck fractures most commonly displace with apex volar angulation and can often be malrotated as well. Very little remodeling potential exists and with the exception of the nondisplaced fractures (which themselves must be watched very closely), these injuries necessitate timely reduction and stabilization.

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1 Brief Clinical History

The patient is a 15-year-old right-hand dominant male who sustained injuries to his left ring and small fingers while playing baseball. He presented acutely with finger pain and swelling. Clear malrotation of his ring finger is appreciated (Fig. 1).

2 Preoperative Clinical Photos and Radiographs

See Fig. 2.

3 Preoperative Problem List

Environmental and seasonal allergies

Surgical history: Tonsillectomy and inguinal hernia repair

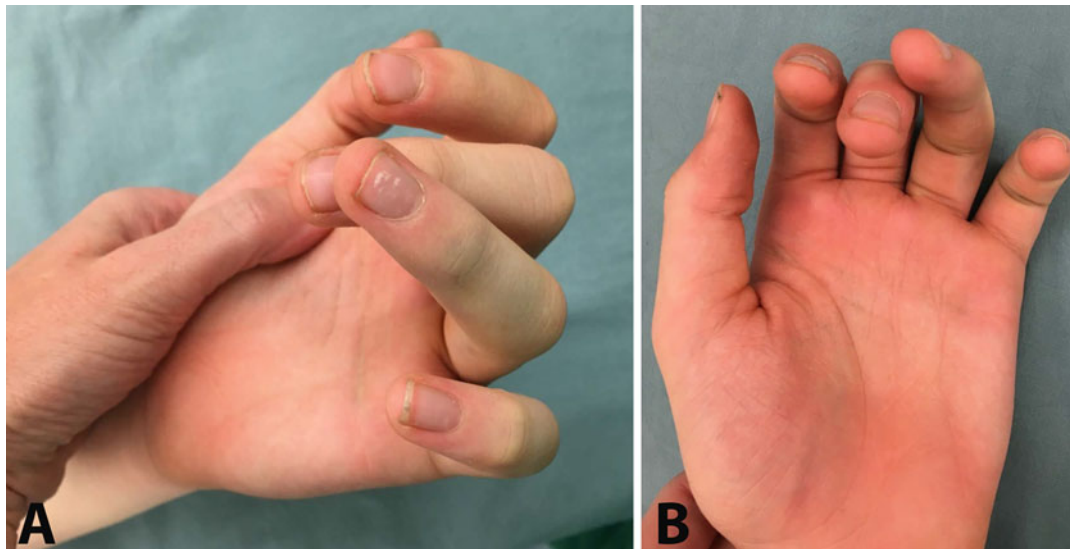


Fig. 1 (a, b) Obvious clinical deformity appreciated with overlapping of the ring and long fingers, and abduction of the small finger

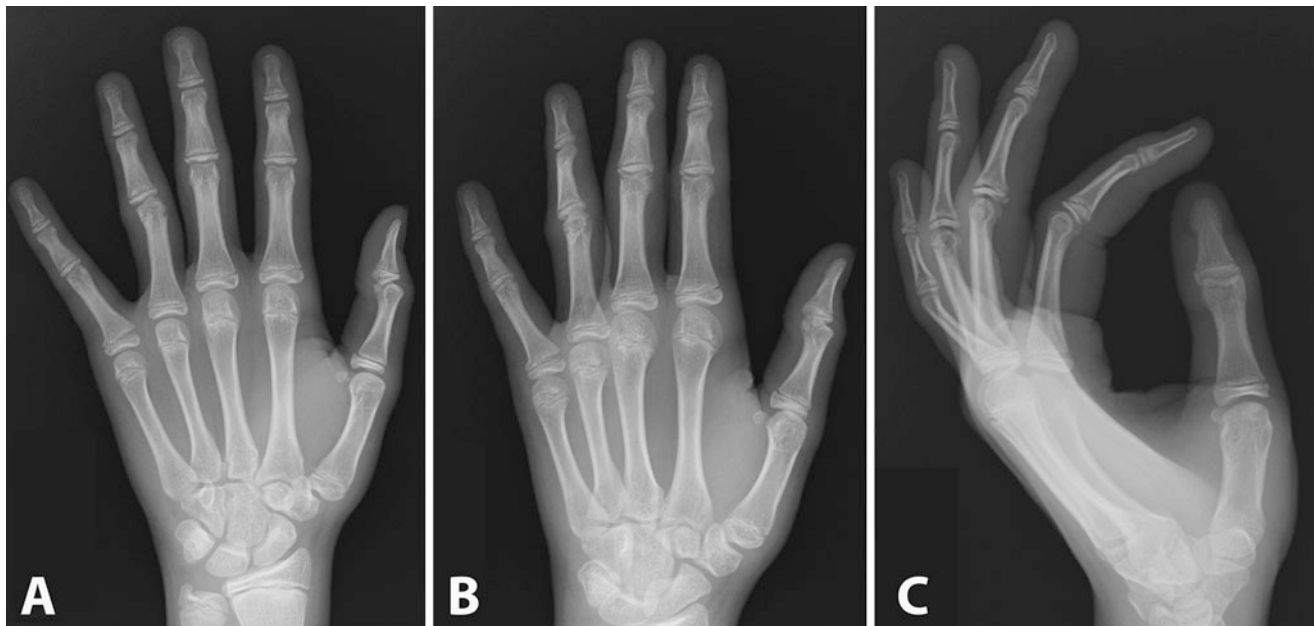


Fig. 2 Anteroposterior (a), oblique (b), and lateral (c) images demonstrating a small proximal phalanx Salter Harris II fracture and a ring proximal phalangeal neck fracture

4 Treatment Strategy

Al-Qattan (2001) developed a classification system to help guide care. The vast majority of acute phalangeal neck fractures can be reduced in closed fashion with pinning in the first 1–2 weeks after injury. Beyond that, the fracture reduction may necessitate *osteoclasis* (Waters et al. 2004) or open technique. Avascular necrosis (AVN) of the condyle(s) is a

considerable risk with intervention after 2 weeks (Topouchian et al. 2003). Without reduction and pinning, the displaced fractures heal with obliteration of the subcondylar fossa, preventing full flexion. The reduction maneuver entails traction, gentle fracture-specific manipulation, and flexion. Pins are placed in retrograde fashion, with cross-pinning the ideal configuration for transverse fractures. Sometimes, however, there is not adequate purchase on one of the condyles, as can be observed with oblique fractures,



Fig. 3 Example of a phalangeal neck fracture, which precludes cross pinning. Oblique (a) and lateral (b) radiographs demonstrating a displaced phalangeal neck fracture. Reduction technique includes traction and flexion (c). Retrograde pins placed from radial border capture

the fragment and maintain reduction (d, e). Final follow-up anteroposterior (f) and lateral (g) radiographs demonstrate healing and re-creation of the subcondylar fossa

and therefore a parallel or divergent configuration must be utilized (Fig. 3). Most fractures can be stabilized with 0.035 in. Kirschner wires, but size selection depends on the age and mass of the child. Pins remain in place under a cast for 4 weeks and are then pulled in clinic.

5 Basic Principles

It is important to maintain ligamentous attachments to preserve the blood supply to the condyles, particularly if an open approach is utilized. Try to minimize trauma to the articular fragment; the more pin passes, the more adhesions can be formed. Avoid excessive manipulation if possible.

6 Images During Treatment

See Fig. 4.

7 Technical Pearls

If it is difficult to achieve the reduction, a point-to-point reduction clamp can be utilized to manipulate the fracture.

The starting point for retrograde pin placement is much more distal than one would expect.

If osteoclasis is necessary, place the K-wire in the concavity of the fracture and utilize an upward force to not only break up

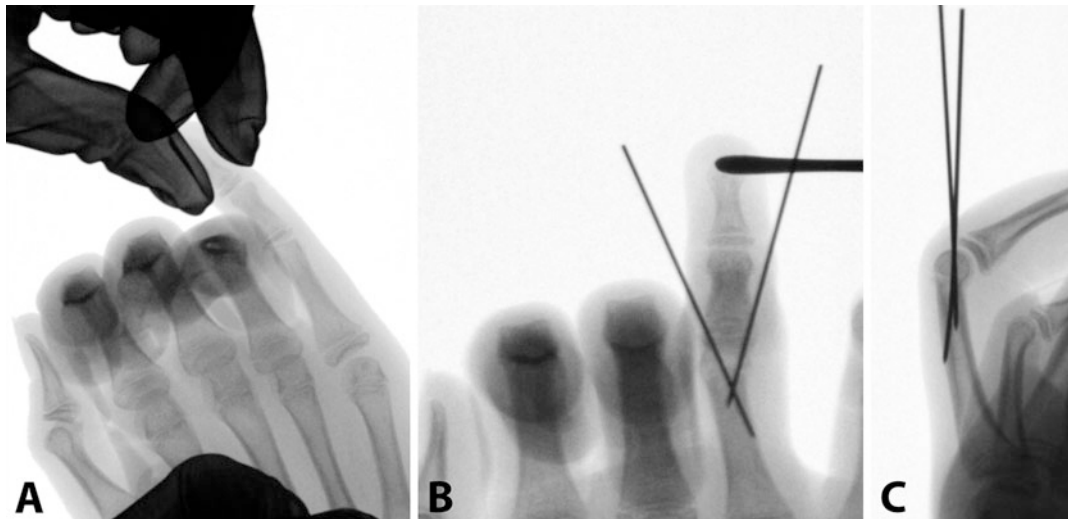


Fig. 4 Closed reduction of the small proximal phalanx base fracture (a) with simple adduction and sometimes flexion at metacarpophalangeal joint. Anteroposterior (b) and lateral (c) images of closed reduction percutaneous cross pinning of the ring proximal phalangeal neck fracture



Fig. 5 Example of a displaced middle phalangeal neck fracture: anteroposterior (a), oblique (b), and lateral (c) radiographs. Closed reduction and percutaneous pinning is performed (d)

with the lateral image (e) demonstrating the flexion required to achieve reduction. Sometimes this leads to iatrogenic flexion contracture

callus but also to try to move the fracture fragment in the desired direction.

Middle phalangeal neck fractures are more difficult because there is not as much flexion at the distal interphalangeal (DIP) joint and excessive flexion can lead to iatrogenic mallet-type deformity (see Fig. 5).

8 Outcome Clinical Photos and Radiographs

See Fig. 6.

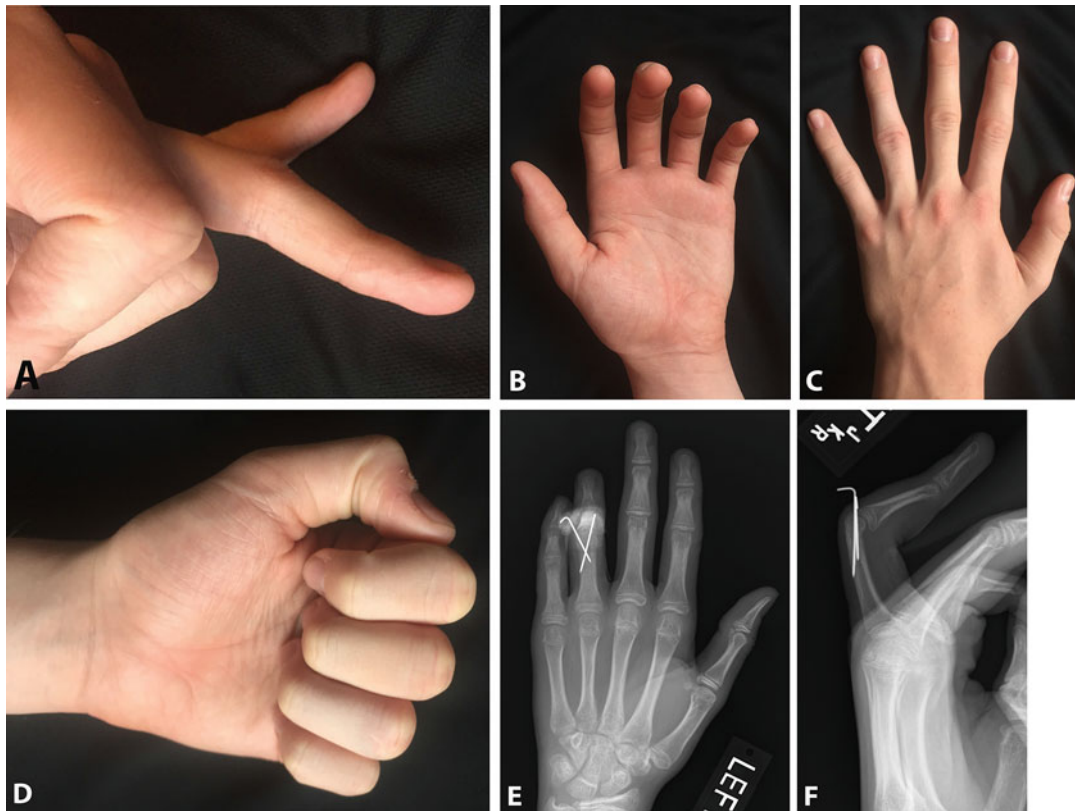


Fig. 6 Final clinical (a–d) and radiographic (e, f) images, demonstrating good alignment and healing

9 Avoiding and Managing Problems

Excessive flexion is sometimes necessary to achieve the reduction and is generally not a problem at the proximal interphalangeal joint, but this can be problematic at the DIP joint for middle phalangeal neck fractures. If maintained for 4 weeks in excessive flexion, it can lead to a flexion contracture. If it is possible to place the joint in neutral after having achieved the reduction, this is preferable. However, if a flexion posture is necessary to maintain the reduction and a flexion contracture occurs, it can be treated with aggressive therapy and extension splinting.

Avascular necrosis of the condyles is seen most commonly with crush injuries, ischemia, congestion, fragmenting the head during closed reduction, and multiple passages through the bone with the K-wire (Al-Qattan 2010). This is a difficult complication to address, so early intervention, attempts at osteoclasts if presentation is >2 weeks, and minimizing disruption to blood supply are the best options to try to prevent AVN.

10 Cross-References

- ▶ [Extra-Octave Fractures](#)
- ▶ [Intra-articular Phalangeal Fractures](#)
- ▶ [Phalangeal Shaft Fractures](#)

References and Suggested Reading

- Al-Qattan M (2001) Phalangeal neck fractures in children: classification and outcome in 66 cases. *J Hand Surg Br* 26:112–121
- Al-Qattan MM (2010) Nonunion and avascular necrosis following phalangeal neck fractures in children. *J Hand Surg Am* 35(8): 1269e–11274
- Topouchian V, Fitoussi F, Jehanno P et al (2003) Treatment of phalangeal neck fractures in children: technical suggestions. *Chir Main* 22:299–304
- Waters P, Taylor B, Kuo A (2004) Percutaneous reduction of incipient malunion of phalangeal neck fractures in children. *J Hand Surg* 29:707–711

Intra-articular Phalangeal Fractures

Helen Shi and Kevin J. Little

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Abstract

A 12-year-old female suffered an intra-articular fracture of the phalangeal head. This fracture is often caused by shearing or torsional forces to the interphalangeal joint sustained during ball handling sports. This fracture may also be seen as a result of falls, crush injuries, or direct blows. These fractures may appear nondisplaced initially, but will frequently displace over time without surgical intervention, and close follow-up is necessary in patients treated nonsurgically. Surgical intervention for displaced condylar fractures typically involves either closed

reduction and percutaneous pinning using Kirschner wires (K-wires), or open reduction and internal fixation using lag screws or K-wires. Early active motion after surgery should be established if possible to minimize stiffness and retain range of motion in the injured joint. Fracture healing occurred in 4 weeks, and she regained full motion at 6 weeks postoperatively with a home exercise program.

1 Brief Clinical History

A 12-year-old female sustained an intra-articular fracture of the phalangeal head during basketball practice. She initially thought her finger was just “jammed” and did not seek care for several days following the injury. She presented with edema and ecchymosis centered over the involved joint

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Fig. 1 Clinical photograph of a 12-year-old female patient with a condylar fracture of the finger with scissoring of the small finger as a result of malrotation

with limited range of motion due to pain and edema. Her finger was tender to palpation at the fracture site. Malrotation of the digit was noted due to fracture displacement (Fig. 1). Because of the intra-articular nature of the phalangeal fracture, the patient required closed reduction and percutaneous pinning of the injured digit (Fig. 2). Open reduction was avoided in this case as a percutaneous reduction could be performed, thereby avoiding the complications of potential joint stiffness and avascular necrosis.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Unstable, displaced articular fracture of the proximal interphalangeal joint
2. Difficult reduction due to oblique fracture plane and delayed presentation
3. Choice of fracture fixation and postoperative immobilization
4. Postoperative rehabilitation to regain full function of the digit.

4 Treatment Strategy

This unstable fracture could not be treated with static splinting or casting. The patient was brought to the OR within 5 days of presentation. Closed reduction was



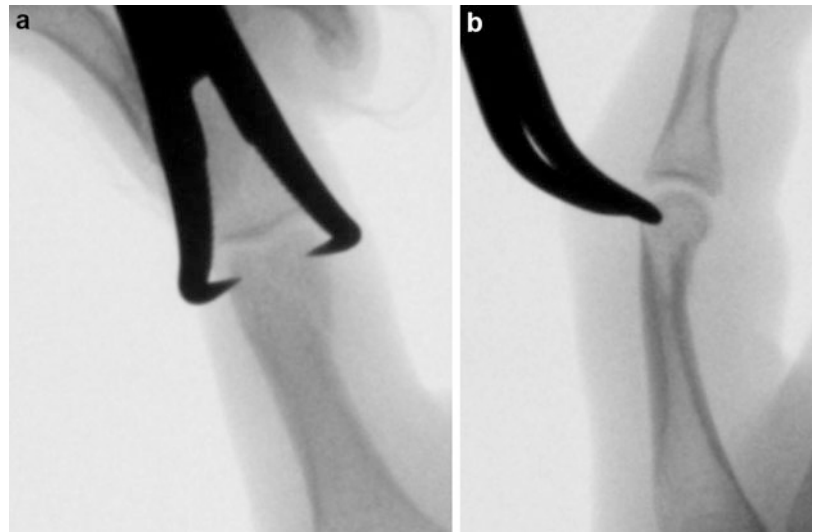
Fig. 2 Anteroposterior (a) and lateral (b) radiographs of a 12-year-old female patient with a displaced unicondylar fracture of the right small finger

attempted with traction and ulnar deviation, but this could not align the articular surface. A tenaculum clamp was used to aid reduction, which successfully restored articular congruity (Fig. 3). Closed reduction with percutaneous pinning (CRPP) using Kirschner wires was used to stabilize the fracture, then the tenaculum clamp was removed. The first K-wire is placed distally and parallel to the joint surface. Two additional divergent K-wires are placed to provide stability. Once adequate reduction and fracture were verified on biplanar fluoroscopy, the pins were bent and cut outside the skin to facilitate easy removal (Fig. 4). The patient was placed in a 2-finger, ulnar gutter cast to return at 4 weeks for pin removal.

5 Basic Principles

1. The goal of surgical treatment is to reduce the fracture such that the articular surface is congruent and level while providing stability to allow for healing. Reduction is frequently accomplished with a closed reduction or augmented by a tenaculum clamp.
2. Longitudinal traction and extension may be required to reduce the fracture. The fracture plane typically runs either obliquely in the sagittal plane or in the coronal plane, such that the K-wires should be placed perpendicular to these fracture planes to impart the most stability.

Fig. 3 AP (a) and lateral (b) fluoroscopic images of the same patient noted in Fig. 2 demonstrating the use of a tenaculum clamp to reduce the fracture and restore articular congruity



3. K-wires are bent and cut short, then covered in a cast. The wires are typically kept in place for 4 weeks to ensure appropriate healing and are easily removed in the office.
4. If open reduction is required, a dorsal incision is best to view the articular surface. The fracture is frequently attached to the collateral ligament and can be reduced with manipulation of the joint combined with direct guidance. Once in anatomical alignment, 2 or 3 lag screws (1.3–2.0 mm) or K-wires are used to stabilize the fracture.

6 Images During Treatment

See Figs. 3, 4, 5, and 6.

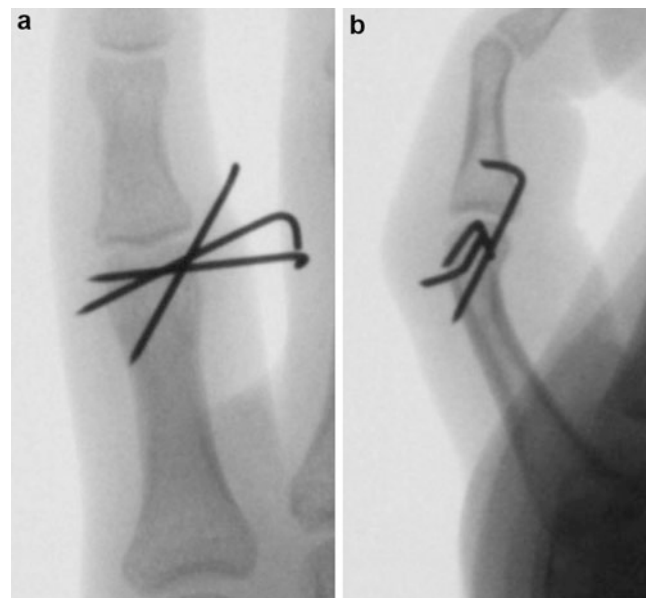


Fig. 4 AP (a) and lateral (b) fluoroscopic images following pin insertion for the patient noted in Fig. 2

7 Technical Pearls

1. For closed treatment in nondisplaced condylar fractures, serial radiographs and examination out of the cast are required to ensure that no subtle displacement or malangulation is occurring. Most condylar fractures will displace volarly and proximally.
2. Percutaneous reduction is preferred as it limits the soft tissue dissection that can compromise vascularity to the condyle. This can be accomplished with a tenaculum clamp or with a k-wire.
3. For coronal plane shear fractures, the wires are started from a more volar starting point, while ensuring that the volar neurovascular bundle is not damaged (Fig. 5).
4. The K-wires may be pulled out the opposite side of the finger if they are blocking collateral ligament excursion and limiting passive range of motion in the operating room (Fig. 5g).
5. Comminuted, bicondylar fractures may require several wires to fix all fracture fragments (Fig. 6)

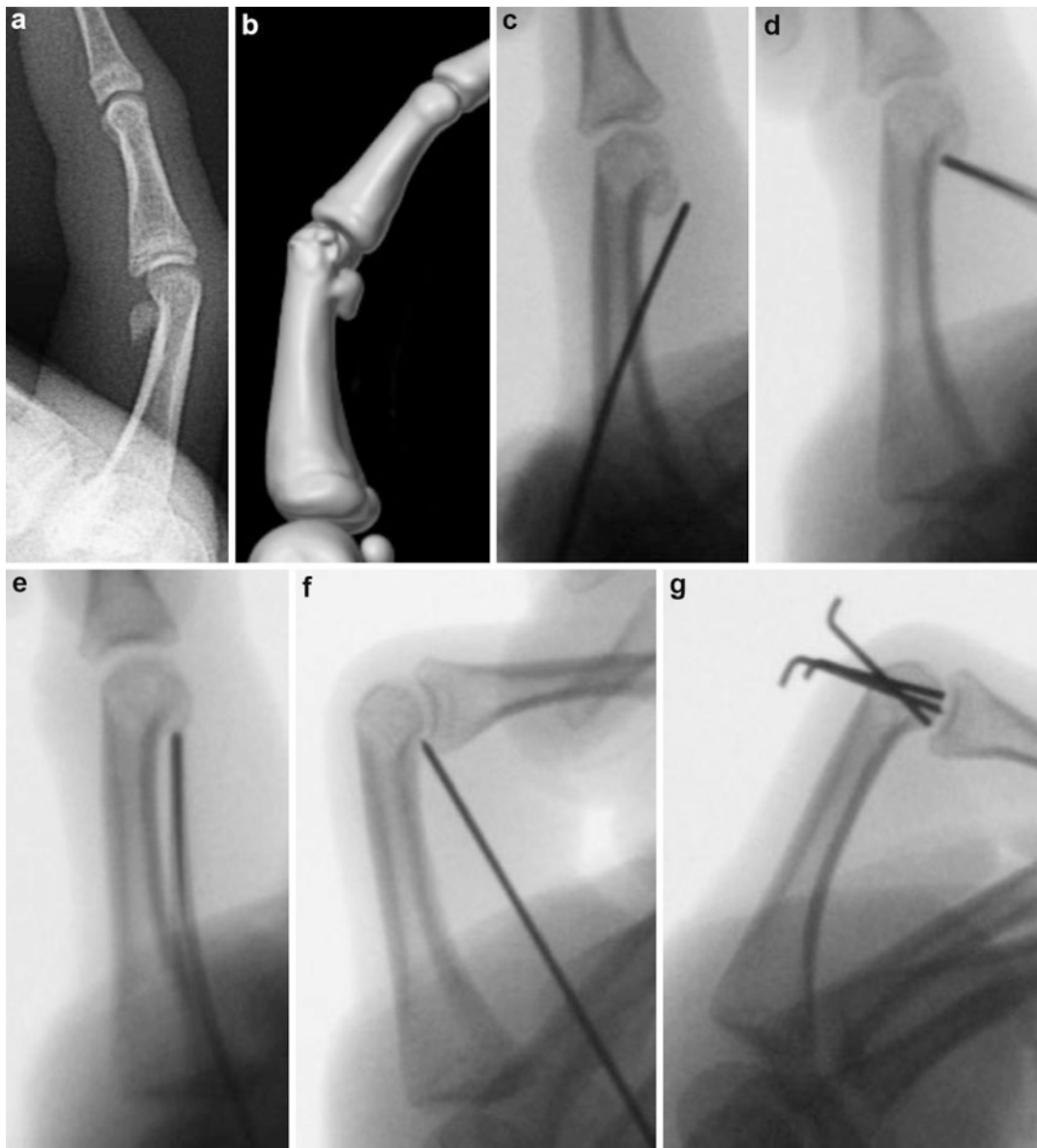


Fig. 5 (a) Lateral radiographs of a 12-year-old male with a displaced shear fracture of the right small finger. Three-dimensional CT scan reconstructions (b) demonstrate the size of the avulsed piece as well as the donor defect on the lateral condyle, which was difficult to assess on radiographs. (c–f) intraoperative fluoroscopic images demonstrating

percutaneous reduction of a coronal shear fracture of the PIP joint in, followed by stabilization and pin fixation with the PIP joint in flexion. (g) The pins are pulled out through the dorsal skin to prevent collateral ligament entrapment

8 Outcome Clinical Photos and Radiographs

See Figs. 7, 8, and 9.

9 Avoiding and Managing Problems

1. Loss of reduction after conservative treatment is a significant problem seen with these fractures. Many fractures

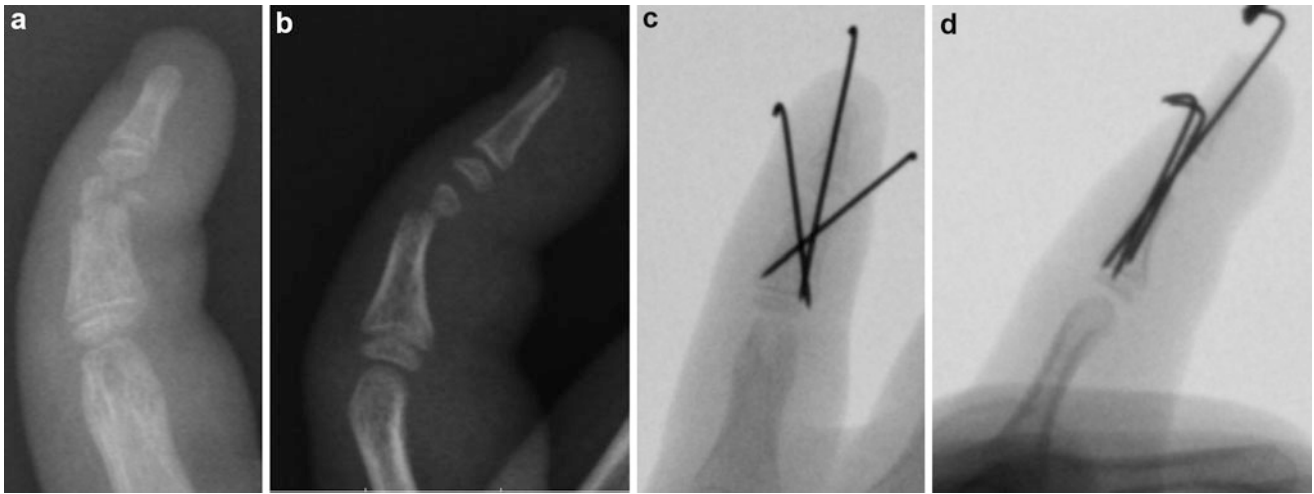


Fig. 6 Anteroposterior (a) and lateral (b) radiographs of a 3-year-old patient with a closed, displaced bicondylar fracture of the left small finger due to a crush injury. AP (c) and lateral (d)

fluoroscopic images following pin insertion to stabilize the bicondylar fracture



Fig. 7 AP (a) and lateral (b) radiographs 1 month postoperatively for the patient noted in Fig. 2. At this point, the pins were pulled and ROM exercises begun

that appear nondisplaced at initial presentation will become displaced if the fracture fragment is not stabilized surgically.

2. Some unicondylar phalangeal fractures treated with a single Kirschner wire will become displaced. This loss of reduction can be mitigated by proactively treating non-displaced fractures with two or more Kirschner wires or lag screws.
3. Occupational therapy is required in some patients after CRPP and in most patients following ORIF to regain functional motion of their digits following surgery (Fig. 8).
4. Proximal interphalangeal joint stiffness is the most common complication patients have with this injury. Stiffness can be diminished by stable fixation and early active digit motion (Bergeron et al. 2005).
5. Avascular necrosis has been noted in patients with unicondylar fractures, especially with significant displacement (Fig. 9). This risk can be mitigated by limiting the amount of soft tissue stripping off the condylar fracture. If this is symptomatic, it can be a difficult problem to treat and may require arthrodesis.
6. Cold intolerance and some chronic aching were sometimes reported by patients during long-term follow-up,

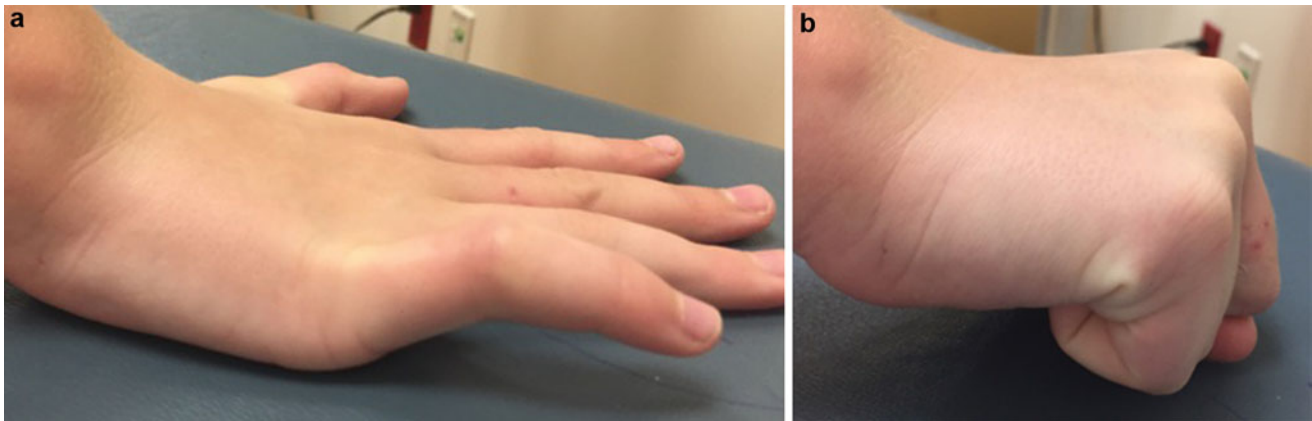


Fig. 8 Extension (a) and flexion (b) photographs taken 3 month postoperatively for the patient noted in Fig. 2. She has regained full passive motion of the joint with a mild PIP extensor lag with active full extension. This required one visit with occupational therapy



Fig. 9 AP (a) and lateral (b) radiographs 1 month and 1 year (c, d) postoperatively for a patient that required ORIF for a condylar shear fracture. He healed, but developed AVN of the condyle with joint

destruction and loss of motion. He elected not to have further surgery as he was able to participate in sports without significant complaints

but these complaints were sporadic and rarely required surgical intervention (Freeland and Sud 2001).

10 Cross-References

- Phalangeal Neck Fractures
- Phalangeal Shaft Fractures

References and Suggested Reading

- Bergeron L, Gagnon I, L'Ecuyer C, Caouette-Laberge L (2005) Treatment outcomes of unstable proximal phalangeal head fractures of the finger in children. *Ann Plast Surg* 54(1):28–32
- Blazar P, Steinberg D (2000) Fractures of the proximal interphalangeal joint. *J Am Acad Orthop Surg* 8:383–390
- Freeland A, Sud V (2001) Unicondylar and bicondylar proximal phalangeal fractures. *J Am Soc Surg Hand* 1(1):14–24
- Weiss A, Hastings H (1993) Distal unicondylar fractures of the proximal phalanx. *J Hand Surg* 18(4):594–599

Seymour Fracture (Open Physeal Fracture of the Distal Phalanx)

Suzanne Steinman

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Abstract

Seymour fracture is a displaced distal phalanx juxta-epiphyseal fracture (Salter-Harris I or II) with an associated nail bed injury. Because of the nail bed injury, this is an open fracture and must be treated accordingly. Its diagnosis is often missed or delayed resulting in long-term complications that can include osteomyelitis, nail growth disturbance, and growth arrest of the distal phalanx. Diagnosis requires knowledge of and appropriate suspicion of the injury. Clinically, the injury resembles a mallet injury but with the nail often lying on top of the cuticle or bleeding from the cuticle noted. Radiographs can then confirm the presence of a displaced distal phalanx fracture. This fracture then must be treated as any other open fracture with antibiotics, irrigation and

debridement, stabilization when needed, and appropriate immobilization.

1 Brief Clinical History

Thirteen-year-old female sustained a jamming injury to her right small finger resulting in a forced hyperflexion of her distal phalanx when she was boating and hit her hand on the boom. She had immediate pain, mallet deformity with the fingernail lying superficial to the eponychial fold and bleeding from her right small finger at the cuticle. She was seen immediately in the emergency department for care (Images 1, 2, and 3).

2 Preoperative Clinical Photos and Radiographs

See Images 1–3

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3 Preoperative Problem List

1. Open Salter-Harris II fracture right small finger distal phalanx
2. Nail bed injury with interposed germinal matrix at fracture site



Image 1 Injury photo of finger. Distal phalanx shows mallet-like flexion deformity. Notice nail and distal phalanx lying on top of eponychial fold

4 Treatment Strategy

Displaced distal phalanx fractures involving the physis with an associated nail bed injury are called Seymour fractures (Al-Qattan 2001; Seymour 1966). Because of the laceration in the nailbed, Seymour fractures must be treated as open fractures. The unique anatomy of the extensor tendon inserting into the epiphysis of the distal phalanx and the flexor digitorum profundus tendon inserting into the metaphysis results in a characteristic flexion deformity at the fracture site that resembles a mallet injury. The displacement of the fracture causes the nail bed injury that can then get trapped at the fracture site with attempts at closed reduction. The key to this injury is that it must be identified correctly. Any displaced juxta-epiphyseal fracture of the distal phalanx with bleeding from the cuticle or disruption of the cuticle, even in the absence of obvious displacement of the nail, must be suspected of being a Seymour fracture. It requires debridement of the fracture site, extraction of the interposed nail bed with repair, fracture reduction and stabilization, and then protection of the nail bed repair and germinal matrix to promote nail regrowth. Failure to recognize and adequately treat these fractures can lead to osteomyelitis, nail growth disturbance, and growth arrest (Krusche-Mandl et al. 2013; Reyes and Ho 2015).



Image 2 AP radiograph of injury. Salter Harris II fracture of distal phalanx



Image 3 Lateral radiograph of injury. Salter Harris II fracture of distal phalanx

5 Basic Principles

First, adequate imaging (AP and lateral radiographs) is required of the injured finger to identify the fracture (Images 2 and 3). It then should be treated as any other open fracture with a dose of appropriate IV antibiotics. The fracture cannot be reduced by simply extending the finger at the fracture site. This results in the nail bed becoming interposed at the fracture site and does not allow for the fracture site to be debrided (Image 1). For best visualization, the nail should be removed to expose the fracture site. The fracture site is then hyperflexed to expose the entrapped nail bed. Often, incisions need to be extended proximally from the paronychia to allow for adequate exposure of the nail bed laceration (Image 4). Once the nail bed has been extricated, the fracture site is irrigated and debrided. Next, the fracture is reduced by extending at the fracture site. If the fracture is unstable, it may require a pin across it into the epiphysis or across the DIP joint to hold it stable (Images 5 and 6). Once the fracture is stably reduced, the nail bed is repaired using absorbable suture (Image 7). Next, either the nail that has been cleaned or a piece of foil, if the nail is not available, is placed as a stent to protect the germinal matrix (Image 8). Finally, the repair needs to be protected. A volar splint should be applied to the involved digit to hold the fracture reduction and then a mitten cast applied to protect the nail repair. If there is no concern for possible infection, then the patient should follow-up at 3 weeks to allow adequate time for the nail bed repair to heal and to not dislodge it with dressing changes. For contaminated injuries where infection is a concern, then the patient should be brought back earlier for wound check and may need oral antibiotics for discharge. Fractures are usually healed by 6 weeks (Images 9 and 10).

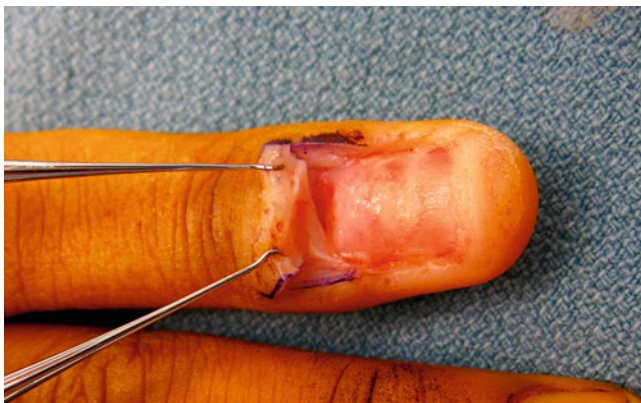


Image 4 Nail bed laceration exposed with extended paronychial incisions

6 Images During Treatment

See Images 4–8

7 Technical Pearls

1. Use adequate sedation as well as local anesthetic
2. Use a tourniquet

Image 5 AP Radiograph of pinned fracture



Image 6 Lateral radiograph of pinned fracture

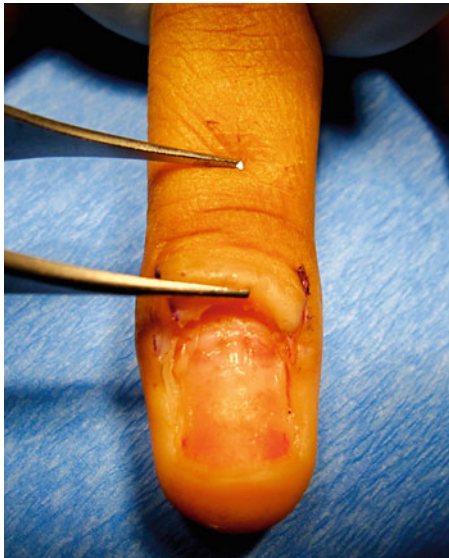


Image 7 Nail bed repair with 6.0 plain gut



Image 9 AP radiograph of healed injury

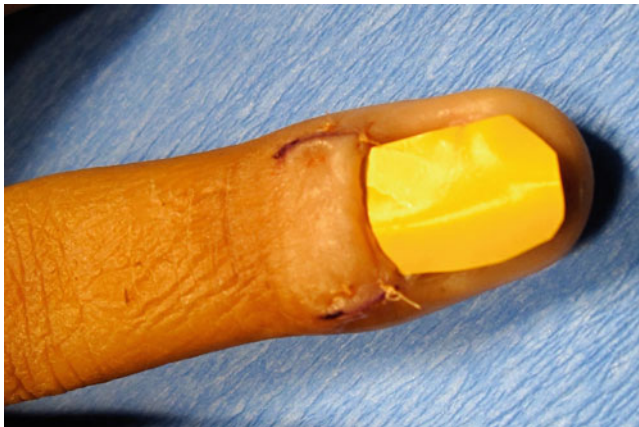


Image 8 Stent in place to protect nail bed repair and germinal matrix

3. Remove nail to get exposure of fracture site and for nail bed repair. Save nail for stent later
4. Make proximal incisions along paronychia to improve exposure if needed
5. Hyperflex fracture site to expose and retrieve interposed nail bed
6. Stabilize fracture with K-wire
7. Use absorbable suture for nail bed repair and stent placement
8. Protect repair with splint and mitten cast

8 Outcome Clinical Photos and Radiographs

See Images [9–15](#)

9 Avoiding and Managing Problems

One of the greatest risks for this injury is infection and osteomyelitis (Reyes and Ho [2015](#)). This can best be avoided by identifying the injury and initial appropriate care with irrigation and debridement and nail bed repair. Signs of infection include pain, swelling, and erythema of the digit or paronychia infection (Image [11](#)). Radiographic examination will often reveal bone resorption at the dorsal physis at the fracture site where osteomyelitis has developed (Images [12](#) and [13](#)). Treatment requires irrigation and debridement with culture of the infected fracture site, nail bed repair, replacement of nail or foil stent, appropriate immobilization, and antibiotics. Other risks with a Seymour fracture include early closure of physis and nail growth disturbance (Images [14](#) and [15](#)) which can both be limited by meticulous fracture care and stabilization and nail bed repair (Krusche-Mandl et al. [2013](#); Reyes and Ho [2015](#)).



Image 10 Lateral radiograph of healed injury



Image 12 AP radiograph of missed Seymour fracture with osteomyelitis 6 weeks from injury



Image 11 Clinical image of missed Seymour fracture with osteomyelitis



Image 13 Lateral radiograph of missed Seymour fracture with osteomyelitis 6 weeks from injury



Image 14 Nail growth disturbance after Seymour fracture



Image 15 Nail growth disturbance after Seymour fracture

10 Cross-References

► [Nailbed Injuries](#)

References and Suggested Reading

Al-Qattan MM (2001) Extra-articular transverse fractures of the base of the distal phalanx (Seymour's fracture) in children and adults. *J Hand Surg Br* 26(3):201–201

Krusche-Mandl I, Kottstorfer J, Thalhammer G, Aldrian S, Erhart J, Platzer P (2013) Seymour fractures: retrospective analysis and therapeutic considerations. *J Hand Surg* 38A:258–264

Reyes B, Ho CA (2015) The high risk of infection with delayed treatment of open Seymour fractures: salter Harris I/II or juxta-epiphyseal fractures of the distal phalanx with associated nail bed laceration. *J Pediatr Orthop* 00:000–000

Seymour S (1966) Juxta-epiphyseal fracture of the terminal phalanx of the finger. *JBJS* 48(2):347–349

Bony Mallet Fractures

Charles L. Long and Jennifer M. Ty

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Abstract

A 14-year-old male sustained a bony mallet injury to his left middle finger during football practice. The fragment involved approximately 50% of the distal interphalangeal joint articular surface and was displaced greater than 2 mm. The patient underwent percutaneous pinning using an extension block technique. The pins were removed at 4 weeks, and the patient was allowed to begin range of motion exercises at that time. At 8 weeks, he was noted to have regained full range of motion, and he returned to sports.

1 Brief Clinical History

A 14-year-old left-hand-dominant male presents for treatment with pain and visible deformity at the distal interphalangeal joint (DIP) of the left middle finger. He reports that he had “jammed” his left middle finger during football practice 1 week ago. He was initially evaluated in a local emergency room where radiographs were obtained demonstrating an intra-articular fracture of the distal phalanx of the patient’s left middle finger. The patient was placed into a finger splint with the distal interphalangeal joint in extension, and he was referred for further treatment. He reports taking the splint off for hand hygiene. On clinical examination, the patient’s DIP joint was noted to be in a flexed position, and he was unable to extend the finger at that joint. The digit was noted to be pink and well perfused without injury to the overlying soft tissues or the nail bed. The patient was tender and swollen over the DIP joint. Radiographs showed an extensor tendon avulsion fracture

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of the distal interphalangeal joint – a bony mallet fracture. The fracture involved approximately 50% of the articular surface, and the fragment was displaced greater than 2 mm.

2 Clinical Photos and Radiographs

See Fig. 1

3 Problem List

1. Bony mallet fracture: distal phalanx avulsion fracture involving the terminal tendon of the extensor digitorum communis
2. Operative and nonoperative treatment options

4 Treatment Strategy

Distal phalanx fractures in the pediatric population have an annual incidence of 2.7% (Naranje et al. 2016). Approximately 18% of these represent bony mallet injuries (Lankachandra et al. 2017). The injury is thought to occur as the result of an eccentric forceful flexion of the distal interphalangeal joint, usually due to axial loading.

The Doyle classification describes a spectrum of mallet injuries (Lin and Samora 2018b). The distal phalangeal

growth plate closes between 13–16 years of age (Chen et al. 2018). Bony mallet injuries in the pediatric and adolescent population can thus present as intra-articular fractures in skeletally mature individuals or physeal injuries in the skeletally immature. These are typically Salter-Harris type III fractures in adolescents (see Fig. 2) or less commonly Salter-Harris type I or II fractures in younger children. Bony mallet fractures may represent a type of transitional fracture as they often appear to involve the physeal scar (Chen et al. 2018). The middle finger is most commonly involved, followed by the ring and index fingers, and males are more often affected than females (Lin and Samora 2018a).

The overall goals of treatment are to restore active DIP extension, maintain DIP flexion, prevent the development of a swan neck deformity, and minimize the risk of post-traumatic growth arrest or arthritis.

Typically, a bony mallet fracture is initially treated with splinting of the distal phalangeal joint in extension in the emergency room or urgent care center.

There has been some controversy as to the indications of operative versus nonoperative management of bony mallet injuries. The size of the bony fragment, amount of DIP joint articular involvement, displacement of the bony fragment, and joint subluxation have all been indicated as factors in treatment decisions. Traditionally, fracture fragment size greater than 30% of the articular surface and volar subluxation of the distal phalanx have been used as indications for surgery (Lin and Samora 2018b).

Fig. 1 AP (a) and lateral (b) radiographs demonstrate a displaced fracture of the distal phalanx of the left middle finger. The bony fragment involves 50% of the articular surface and is displaced greater than 2 mm



However, a recent systematic review of surgical and non-surgical management of soft tissue and bony mallet injuries in adults (Lin and Samora 2018b) concluded that there was insufficient evidence to determine when surgery was indicated and that overall both surgical and nonsurgical treatments led to comparable outcomes.

A separate review of pediatric soft tissue and bony mallet injuries (Lin and Samora 2018a) reported overall good outcomes with treatment with extension orthoses. However, this was a retrospective study which mainly focused on residual extensor lag as an outcome measurement. Of note, the authors did describe that the single patient that they reported

with a poor outcome presented late with a fracture involving nearly 50% of the articular surface. The sole operatively managed case was a patient with a fracture involving 50% of the articular surface and volar subluxation. Again, the authors concluded that indications for surgery remain unclear.

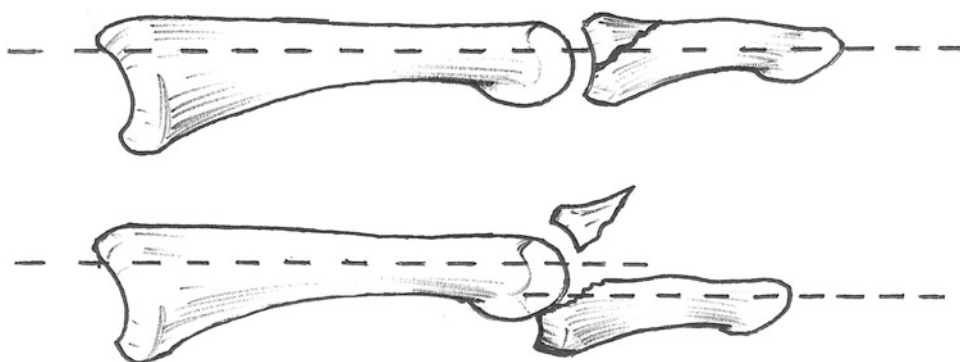
We discussed treatment options with the patient and his family and recommended surgical management given the degree of joint involvement.

Many different percutaneous and open surgical techniques have been described for the treatment of bony mallet fractures. The author's preference is a modification of the dorsal blocking pin technique originally described by Ishiguro (Ishiguro et al. 1997). The patient was brought to the operating room, and general anesthesia is induced. A digital block with ropivacaine 0.2% is administered. The proximal interphalangeal (PIP) and DIP joints are maximally flexed. A 0.035 or 0.045 K-wire is passed through the extensor tendon 1–2 mm above the fracture fragment and directed into the head of the middle phalanx. The DIP joint is then extended with a dorsally directed force reducing the fracture, and a second Kirschner wire (0.035 or 0.045 in.) is inserted retrograde into the tip of the distal phalanx through the middle phalanx pinning the DIP joint in extension. The patient is subsequently placed into a cast to protect the pins.



Fig. 2 SH type III bony mallet fracture in a patient with minimally open distal phalangeal growth plates

Fig. 3 Illustration of late joint subluxation. (Drawings by Charles L. Long)



5 Basic Principles

1. Overall goals of treatment are to restore active DIP extension, maintain DIP flexion, prevent the development of a swan neck deformity, avoid subluxation of the DIP joint, and minimize the risk of post-traumatic growth arrest or arthritis.
2. “Traditional” surgical indications include fracture fragment size >30–50% of the articular surface, and displacement >2 mm.
3. Fragment size >30–50% of the articular surface is thought to place the patient at risk of late joint subluxation (see Figs. 3 and 4).

4. Recent systemic reviews suggest that the evidence for these treatment indications is insufficient, and many patients do well with nonoperative management. Some studies have suggested that patients may have good results with significant involvement of the articular surface and even distal phalanx subluxation.
5. Patients typically have a slight residual distal interphalangeal joint extensor lag of 6–8°, but they usually have excellent clinical outcomes (Lin and Samora 2018b).

6 Images During Treatment

See Figs. 5, 6, and 7.

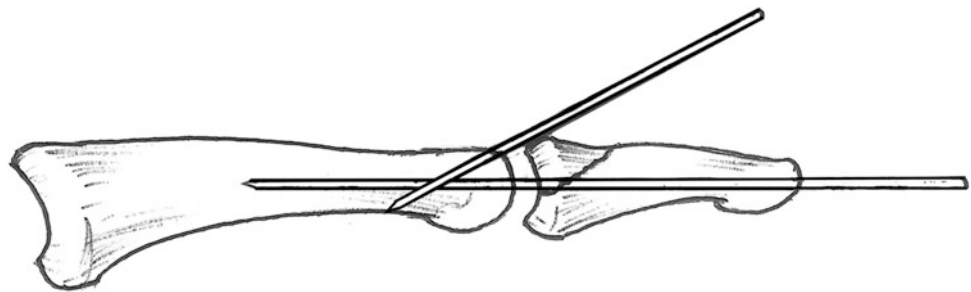
7 Technical Pearls: Operative Treatment

1. Patients should be counselled that a slight extensor lag and a “bump” – a bony or soft tissue prominence at the level of the level of the fracture – can be expected.



Fig. 4 Lateral radiograph of a different patient showing joint subluxation with a fracture fragment approximately 40% of the articular surface

Fig. 5 Illustration of the Ishiguro method. (Drawings by Charles L. Long)



2. With the Ishiguro technique, it is important to be careful when bending the dorsal blocking pin. If the pin is bent away from the fracture, it may lose the compressive “blocking” force, and the fracture may displace. This can be avoided by not bending the pin or by bending the pin toward the fracture.
3. Fractures that present subacutely (3–5 weeks) may require an open procedure or a percutaneous “freshening” of the fracture by gently scraping the fracture site with a K-wire to remove fibrous tissue interposed in the fracture site. Use care to avoid damage to the articular surface of the middle phalanx.
4. Many other open and percutaneous techniques have been described for treatment of bony mallet fractures.
5. Open procedures can be complicated by infection or injury to the germinal matrix causing nail deformity.
6. Pins can be typically be removed at 4 weeks. Range of motion exercises can be started at this time.

7.1 Technical Pearls: Nonoperative Treatment

1. As with operative management, patients should be counselled that a slight extensor lag or a “bump” at the level of the fracture can be expected.
2. Nonoperative treatment of bony mallet fractures usually consists of full-time immobilization with a splint in full extension or slight hyperextension \times 4 weeks, followed by nighttime splint \times 2 weeks (see Fig. 8).
3. Commercially available splints such as the Stack orthosis, custom thermoplastic orthoses, or aluminum splints customized for the patient may be used.
4. Splinting can be associated with skin irritation or skin breakdown.
5. Compliance with full-time wear can be a problem with the pediatric and adolescent population. Studies have shown that adherence to the full-time wear protocol is associated

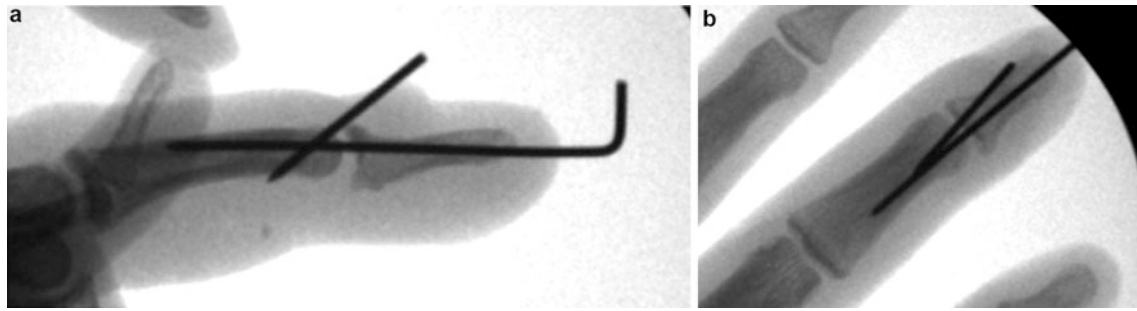


Fig. 6 Lateral (a) and AP (b) intraoperative fluoroscopy images

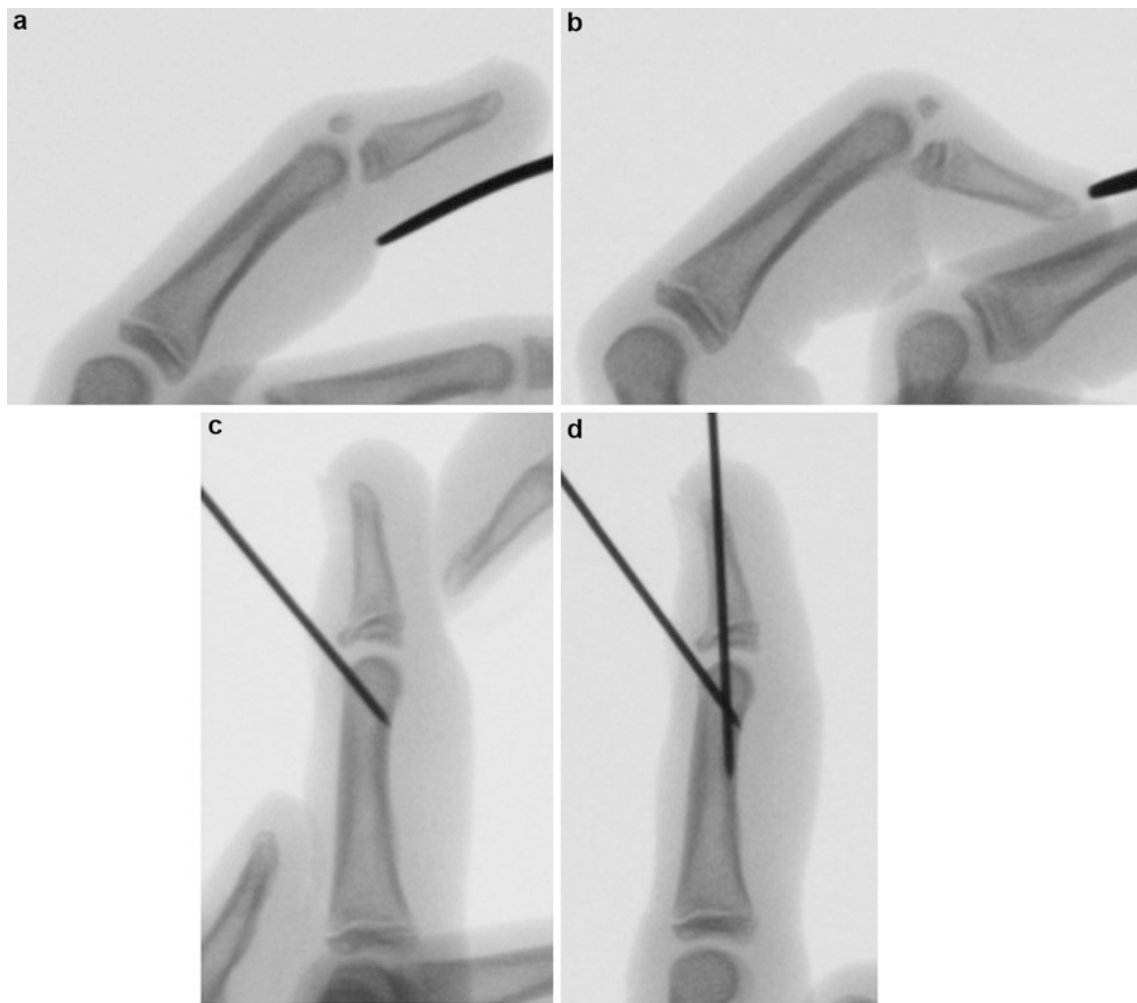


Fig. 7 (a–d) Images during pinning via the Ishiguro technique of a different patient



Fig. 8 (a–c) A 13-year-old right-hand-dominant male with a past medical history significant for attention deficit hyperactivity disorder presents with a left ring finger bony mallet injury. (a) Lateral XR at presentation. He was placed into a customized aluminum splint to maintain the DIP in full extension. Given the patient's age, comorbidities, and the family's estimation regarding adherence, this was covered with an ulnar gutter cast

including the middle, ring, and small fingers. (b) Lateral XR during treatment. The splint and cast were discontinued at 4 weeks, and the patient was treated with a removable Stack splint. He was instructed to wear this full-time wear with removal for hand hygiene only for 2 additional weeks. (c) The patient was noted at 6 weeks to have evidence of fracture healing, and he was allowed to advance his activities

Fig. 9 (a) AP radiograph at 4 weeks. (b) Lateral radiograph at 4 weeks

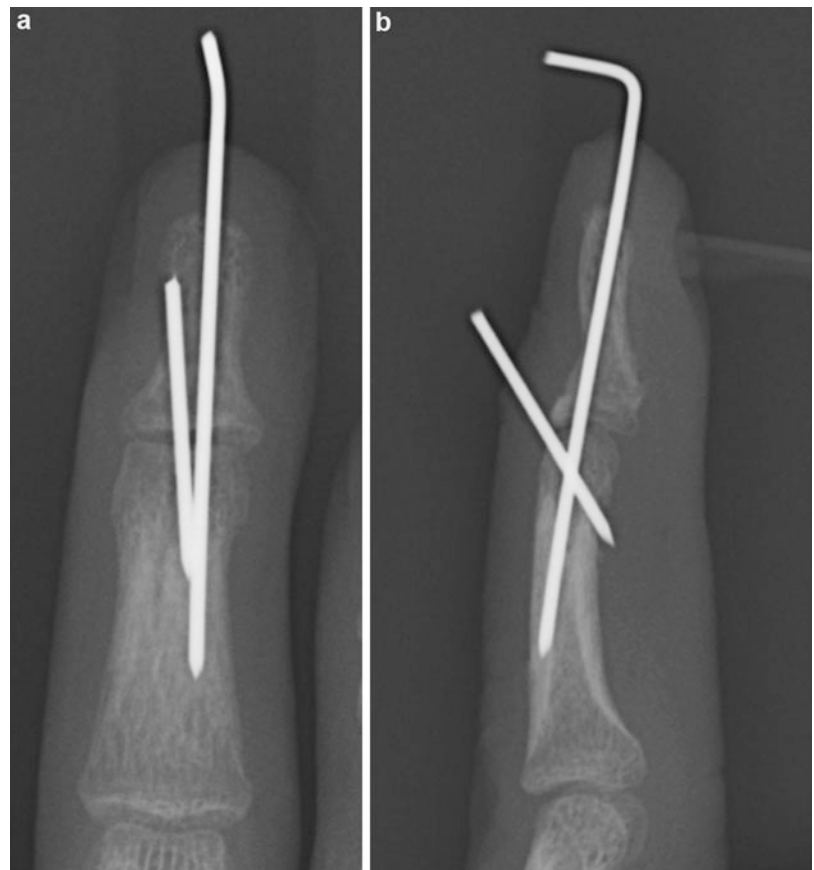


Fig. 10 (a) AP radiograph at 8 weeks. (b) Lateral radiograph at 8 weeks



with smaller degree of residual extensor lag and fewer complications.

6. Patients at high risk of nonadherence to full-time splinting due to age, behavioral, or psychiatric comorbidities may be placed into a customized aluminum splint which is covered by and protected with a cast.
7. There is some data to suggest that even patients with “malunited” bony mallet fractures or “nonunited” bony mallet fractures with a high degree of articular involvement and even joint subluxation may clinically do well. Late-presenting bony mallet in these circumstances may benefit from a trial of nonoperative management.

8 Outcome Clinical Photos and Radiographs

Radiographs at 4 weeks showed evidence of fracture healing. The pins were removed in the office at this time, and the patient was instructed to begin range of motion exercises (Fig. 9).

At 8 weeks, the patient returned for clinical evaluation. He was noted to have full range of motion at the DIP joint. He was allowed to return to sports and activities (Fig. 10).

9 Avoiding and Managing Problems

Overall, surgical and nonsurgical management of bony mallet fractures is associated with good-excellent clinical outcomes. A slight extensor lag of 5–10° and a residual dorsal “bump” are common, but the clinical significance of this is unclear. Some data suggests that residual extensor lag does not correlate with patient satisfaction scores (Lin and Samora 2018b). Likewise, there is evidence suggesting that “malunited,” nonunited bony mallet fractures and even mallet injuries with distal phalanx subluxation may do well.

Splint treatment may rarely be complicated by skin breakdown. Nonadherence to full-time splinting also appears to correlate with a greater degree of extensor lag. Wound infections and nail deformity are the most common surgical complications; these problems may be minimized by meticulous technique and a minimally invasive approach and fixation.

References and Suggested Reading

- Chen AT, Conry KT, Gilmore A, Son-Hing JP, Liu RW (2018) Outcomes following operative treatment of adolescent mallet fractures. *HSS J* 14(1):83–87. <https://doi.org/10.1007/s11420-017-9563-7>. Epub 2017 May 25
- Ishiguro T et al (1997) Extension block with Kirschner wire for fracture dislocation of the distal interphalangeal joint. *Tech Hand Upper Extrem Surg* 1(2):95–102
- Lankachandra M et al (2017) Complications of distal phalanx fractures in children. *J Hand Surg* 42(7):574.e1–574.e6
- Lin JS, Samora JB (2018a) Outcomes of splinting in pediatric mallet finger. *J Hand Surg* 43(11):1041.e1–1041.e9
- Lin JS, Samora JB (2018b) Surgical and nonsurgical management of mallet finger: a systematic review. *J Hand Surg* 43(2):146–163
- Naranje SM et al (2016) Epidemiology of pediatric fractures presenting to emergency departments in the United States. *J Pediatr Orthop* 36(4):e45–e48

Distal Fingertip Amputations: Local Wound Care

Nancy J. Moontasri, Rameez A. Qudsi, and Jennifer M. Ty

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Abstract

An 11-year-old right hand dominant male presents with a left thumb transverse fingertip amputation. Radiographs do not reveal any evidence of bony injury. The patient is treated with local wound care. At 6 weeks, the wound has healed by secondary intention. At his 6 month follow-up evaluation, he has a good cosmetic and functional outcome.

1 Brief Clinical History

An 11-year-old male presents to the office with a left thumb transverse fingertip amputation after getting the thumb caught in a folding chair earlier that day (Fig. 1a, b). The patient was initially evaluated in a local emergency room where the wound was irrigated and a dressing was placed. The family does bring with them the amputated part which has been placed on ice. Ischemia time is estimated to be approximately 4 h. On examination, the patient is able to actively flex and extend the thumb at the interphalangeal joint. The finger is pink and well perfused. The wound is clean and has minimal bleeding. Radiographs are obtained and show no evidence of bony involvement (Fig. 2a–c).

2 Clinical Photos and Radiographs

See Fig. 1a, b and Fig. 2a–c.

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Fig. 1 (a, b) 11-year-old boy with thumb distal tip amputation and treatment with local wound care and healing by secondary intention. Photographs of the thumb at initial presentation



Fig. 2 (a–c) Radiographic images show distal thumb fingertip amputation without evidence of bony injury

3 Problem List

1. Distal fingertip amputation
2. Treatment options:
 - Microvascular fingertip replantation
 - Revision amputation and primary wound closure
 - Advancement flaps or regional flaps
 - Reattachment of the amputated segment as a composite tissue graft
 - Local wound care and healing via secondary intention

4 Treatment Strategy

Fingertip amputations in a child are a relatively common injury that can be managed in several ways. To achieve the overall goals of a good functional and cosmetic outcome, treatment should focus on preserving length and sensibility, preventing or minimizing nail deformity, and avoiding a painful neuroma or an atrophic fingertip.

Immediate revision amputation and wound closure can be performed for fingertip amputations. However, this often

requires shortening of the finger to allow for wound closure. Advancement flaps and regional flaps can also be performed, but these usually require at least one and sometimes two formal operative procedures, and can need a lengthy period of immobilization (Lee et al. 2013).

Some centers have reported good success with microvascular replantation at the fingertip level (Yamano 1985; Kim et al. 1996). However, the technical challenges of repairing such small vessels, the need for sometimes lengthy hospitalizations for monitoring and care, and the availability of less complicated treatment modalities have limited this from becoming widespread.

More commonly, reattachment of the distal portion of the fingertip as a composite tissue graft without attempting microvascular reanastomosis has been performed. Although these composite grafts have been noted to frequently not survive or only partially survive, the cosmetic and functional outcomes are reported to be good, patient satisfaction is high, and the likelihood of requiring additional reconstructive procedures is low (Borrelli et al. 2018; Eberlin et al. 2014). Reattachment of the fingertip as a composite graft can easily be performed in the emergency room under local anesthesia or conscious sedation, minimizing the cost of treatment.

Distal fingertip amputations can also be addressed with local wound care and healing via secondary intention. There are reports of children and adults regenerating a substantial portion of the fingertip even in instances where the bone is exposed (Krauss and Lalonde 2014; Hoigné et al. 2014). Any of a number of wound care modalities can be chosen to maintain a clean, moist, and

occlusive environment to promote granulation tissue and regrowth of the fingertip.

Given the overall good reported outcomes and simplicity of treatment, it is the author's preference to treat distal fingertip amputations with either reattachment of the detached segment as a composite tissue graft or local wound care and healing via secondary intention. Both options can be discussed with the family, and the family's preferences regarding replantation of the amputated part and/or willingness and ability to perform local wound care may influence the decision regarding treatment.

The family elected to proceed with local wound care. The patient and family were shown how to perform twice daily cleaning of the wound and dressing changes to promote granulation tissue and healing. The family was instructed in the following wound care protocol:

1. Clean the wound by soaking the tip of the thumb in hypochlorous acid wound care solution for 2 min and then gently pat the wound dry.
2. Apply a small amount of hydrogel to the wound to maintain a moist healing environment, and dress the wound with nonadherent petroleum impregnated mesh dressing followed by a gauze wrap.

The patient was followed weekly (Fig. 3a–e). At the 5-week follow-up, there was some evidence of hypertrophic granulation tissue (Fig. 3f, g). This was addressed with discontinuation of the hydrogel and daily application of steroid ointment (clobetasol propionate ointment 0.05%). The wound was noted to be healed at 6 weeks (Fig. 3h).



Fig. 3 Clinical images at (a) 1-week, (b, c) 3-weeks, (d, e) 4-weeks, (f, g) 5-weeks, and (h) 6-week follow-up visits. Steroid ointment was administered at the 5-week point for evidence of hypertrophic granulation tissue

5 Basic Principles

- Fingertip amputations are common injuries in the pediatric population.
- Formal microvascular fingertip replantation, immediate revision amputation and wound closure, and local advancement or regional flap creation can all be used to address a fingertip amputation. However, these treatments may require formal operative intervention and/or hospitalization or require shortening of the finger.
- Reattachment of the amputated segment as a composite tissue graft and local wound care and healing via secondary intention have good reported clinical outcomes. Even in cases of exposed bone, local wound care can often result in excellent tissue regrowth and coverage. Treatment can be initiated and managed in the outpatient setting, thus minimizing cost.

6 Images During Treatment

See Fig. 3a–h.

7 Technical Pearls

1. Fingertip amputations in the pediatric population can be treated simply on an outpatient basis by local wound care and healing by secondary intention or reattachment of the amputated portion as a composite graft.
2. There is no clear evidence that either treatment is superior. Patient and family preferences regarding reattachment of the amputated part and willingness to perform wound care may influence the choice of treatment.
3. Families should be counselled about the possibility of complications such as cold intolerance, fingertip sensitivity, and nail deformity or other cosmetic concerns. They can be reassured that the reported need for additional reconstructive surgery with these treatment modalities is low.

Technical Pearls – Reattachment as a Composite Graft

1. A digital block with ropivacaine or lidocaine should be performed. Younger children usually benefit from conscious sedation. The wound should be thoroughly irrigated and cleaned.
2. The amputated segment should be examined. This should also be cleaned and irrigated. Debris and any clearly devitalized tissue should be removed.
3. The composite graft is reapproximated with interrupted 4-0 chromic suture.
4. A sterile dressing and cast or splint is applied.

5. Families should be extensively counselled that the composite graft can be expected to appear either partially or completely appear nonviable during follow-up. Despite the poor appearance and “take” of the graft, healing usually occurs under the nonviable appearing tissue. It is not clear whether this is due to partial graft survival and take of the underlying tissue in direct contact with the finger or whether there is healing by secondary intention occurring with the graft simply acting as a biologic dressing.
6. A wound check is performed during the first week.
7. The author prefers to replace the cast at the first week for a total of 10–14 days of casting to allow the composite graft to stabilize. At this time, the dressing can be minimized and the child allowed to return to activity. If the graft does not take and becomes established as a biologic dressing, it may take 5–6 weeks for the eschar to fall off. The underlying finger is usually almost completely healed at this point in time.

Technical Pearls – Local Wound Care

1. Most of the studies describing local wound care and healing via secondary intention recommend protocols aimed at keeping the fingertip clean and moist to optimize healing either with a daily dressing change or an occlusive dressing.
2. A finger or hand based splint can be used initially to protect the digit.
3. Families can be counselled that the initial sensitivity of the finger to the dressing change usually improves quickly (within 1–2 days) and that the dressing changes are usually well tolerated.
4. To minimize the need for frequent office visits, families can be instructed to send weekly photographs of the fingertip for evaluation.

8 Clinical Outcome Photos and Radiographs

See Fig. 4a–c and Fig. 5a–c.

9 Avoiding and Managing Problems

1. Hypergranulation or persistent granulation can develop during the healing of the fingertip by local wound care and secondary intention. This excessive granulation tissue can impede epithelization of the wound. This can be addressed by the application of a very small amount of corticosteroid ointment to the granulation tissue daily. If this treatment is initiated in very young children, a lower potency steroid such as hydrocortisone 1% should be

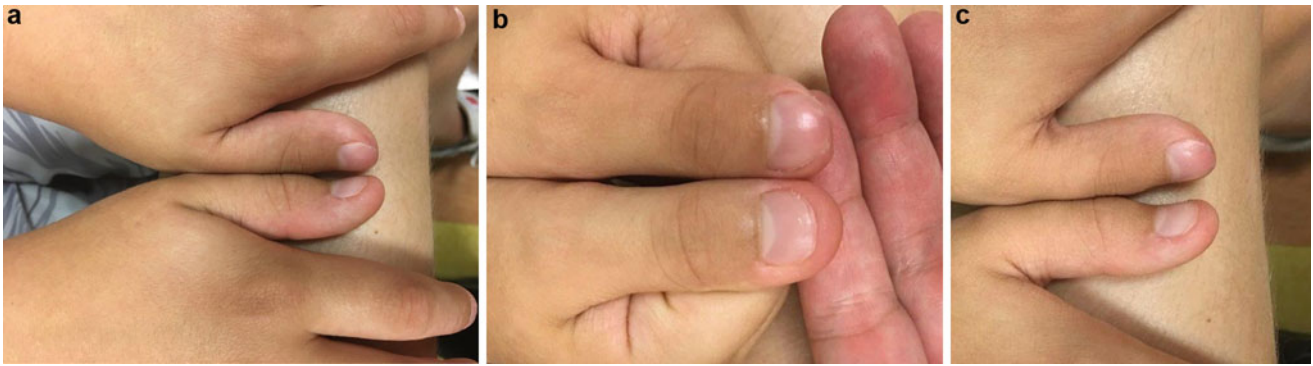


Fig. 4 (a–c) At 6 months after injury, the patient has good function with good range of motion. The finger has good sensibility with no hypersensitivity and a good cosmetic outcome

Fig. 5 A 14-month-old female sustains a left middle finger fingertip amputation with exposed bone. The fingertip is replaced as a composite tissue graft. (a, b) Radiographs showing extent of soft tissue injury. (c, d) The composite tissue graft did not “take.” However, at 3 weeks, there is nice regeneration of the soft tissue with a good contour of the fingertip. There is a small portion remaining of the original now necrotic replaced fingertip

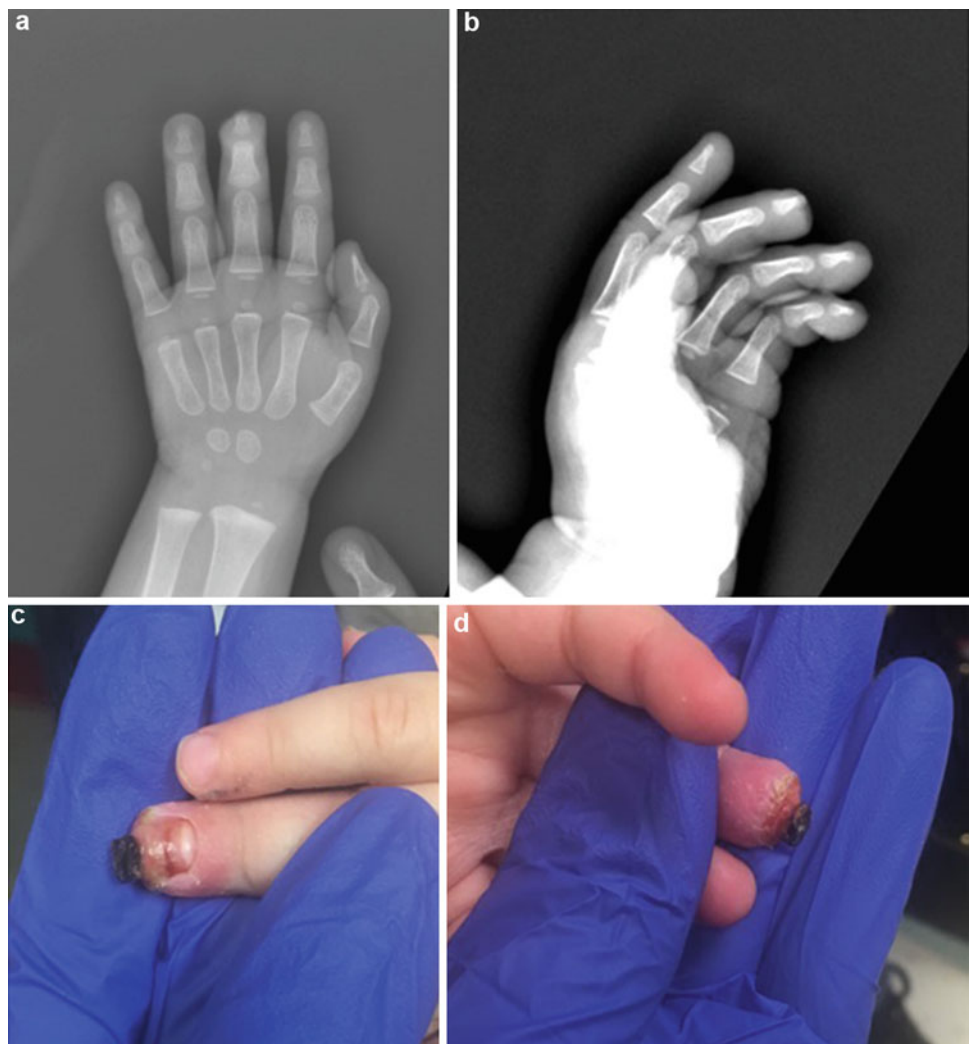




Fig. 6 Mild hooknail deformity after treatment of a distal fingertip amputation with local wound care and healing via secondary intention. Although clinically apparent, the patient had no functional problems with the finger and the family was not concerned enough about the appearance to want to have this addressed surgically

initially trialed to minimize the potential effects of systemic absorption of the steroid.

2. If the injury occurs through the nailbed, a hooknail deformity can occur (Fig. 6). Lack of bony support and wound contracture during healing can cause the nail matrix to grow over the tip of the finger. When mild, this may be well-tolerated (Fig. 6). Several surgical techniques have been described to address a hooknail deformity.
3. Cold intolerance is commonly reported with fingertip injuries, but families can be counselled that this usually spontaneously improves over time.
4. If the soft tissue envelope does not sufficiently regenerate, loss of the distal fingertip cushioning may result in a painful

atrophic fingertip. Neuromas can also develop. These complications can be addressed with surgical exploration, neuroma excision and more proximal nerve transection, and revision amputation or regional flap closure.

10 Cross-References

- [Nailbed Injuries](#)
- [Seymour Fracture \(Open Physeal Fracture of the Distal Phalanx\)](#)

References and Suggested Reading

- Borrelli MR, Dupré S, Mediratta S, Bisquera A, Greig A (2018) Composite grafts for pediatric fingertip amputations: a retrospective case series of 100 patients. *Plast Reconstr Surg Glob Open* 6(6):e1843. Published 2018 Jun 19
- Eberlin KR, Busa K, Bae DS, Waters PM, Labow BI, Taghinia AH (2014) Composite grafting for pediatric fingertip injuries. *Hand (NY)* 10(1):28–33
- Hoigné D, Hug U, Schürch M, Meoli M, von Wartburg U (2014) Semi-occlusive dressing for the treatment of fingertip amputations with exposed bone: quantity and quality of soft-tissue regeneration. *J Hand Surg Eur Vol* 39(5):505–509
- Kim WK, Lim JH, Han SK (1996) Fingertip replantations: clinical evaluation of 135 digits. *Plast Reconstr Surg* 98(3):470–476
- Krauss EM, Lalonde DH (2014) Secondary healing of fingertip amputations: a review. *Hand (NY)* 9(3):282–288
- Lee DH, Mignemi ME, Crosby SN (2013) Fingertip injuries: an update on management. *J Am Acad Orthop Surg* 21(12):756–766
- Yamano Y (1985) Replantation of the amputated distal part of the fingers. *J Hand Surg Am* 10(2):211–218

Nailbed Injuries

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Abstract

The nail functions to protect the fingertip, manipulate small objects, and provide tactile sensation. Without the nail, the distance for two-point discrimination widens. Nail bed injuries are common and are usually the result of direct trauma, such as crushing, pinching, or contact with sharp objects. Injuries can include nail bed avulsions, lacerations, or subungual hematomas. Patients usually present with pain and sometimes bleeding, either as a subungual hematoma or active bleeding around the eponychium. Radiographs should be utilized to evaluate the underlying bony anatomy, as distal phalanx tuft fractures, Seymour fractures, and distal interphalangeal joint dislocations can be associated with nailed injuries. Examination of the injury should include evaluation of sensation, motor function, and vascular supply. Nail bed

injuries are often treated in outpatient, urgent care, or ED settings, with the common goal to restore proper growth of the nail and prevent secondary deformities. The use of antibiotics varies among providers, and depends on the extent of injury and timing of evaluation. It is relatively common to prescribe antibiotics when the bone or joint is exposed below a nail bed injury. Removal of the nail plate to evaluate the nail bed remains controversial, but there are a few scenarios that require nail plate removal, such as acute Seymour fractures, and when the nail bed rests above the eponychium. Repair of the nail bed can be achieved with suture or with a topical skin adhesive such as Dermabond. The prognosis of the nail bed depends on its ability to heal and the type of injury. Severe injuries may lead to scarring, deformity, and nonadherence of the nail. It can take several months for the nail to remodel.

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1 Brief Clinical History

A 15-year-old male sustained a laceration through his dominant right thumb nail plate secondary to a knife injury. The nail plate was clearly cut through and through, and the laceration extended into the eponychium matrix. Radiographs did not demonstrate any osseous abnormalities.

2 Preprocedure Clinical Photos and Radiographs

Figure 1 demonstrates the injury to the thumb nail plate extending into the eponychium.

3 Preoperative Problem List

No allergies
No previous hand/nail trauma
No medical conditions

4 Treatment Strategy

Not every nail plate needs to be removed to evaluate the matrix. In recent years, there has been variation among providers on removal of the nail plate when there is a subungual hematoma. Traditional teaching was that if the bleeding covered greater than 50% of the nail bed surface, the nail plate



Fig. 1 Longitudinal laceration directly through the nail plate into the matrix

should be removed to evaluate the nail bed (Tos et al. 2012). However, more recently, less aggressive treatment has been advocated (Ramirez and Means 2011). If a chronic subungual hematoma is present, there is certainly no need for nail plate removal. Early on, however, a perforation could be made in the nail plate with an 18-gauge needle, a thin blade, or electrocautery device, which may enable evacuation of the blood and reduce pain by decreasing the pressure.

Figure 2a demonstrates a subungual hematoma, which does not necessarily require nail plate removal. In the case of Seymour fractures or when the nail bed rests superficial to the eponychium (Fig. 2b), nail plate removal is indicated. In the case of a laceration or more traumatic injury to the fingertip and nail (as seen in Fig. 2c), the provider may choose to remove the nail plate in order to evaluate the injury to the nail bed and to repair the laceration.

Once it has been decided to remove the nail plate, it should be removed prior to creating any cutbacks on the eponychium. A digital block is placed using a fast-acting anesthetic such as Lidocaine. The nail can then be removed by rotational movements using either Littler scissors or a freer elevator to elevate the nail plate (Tos et al. 2012). Care should be taken to direct the instrument away from (or dorsal to) the nail bed, so as not to create further injury. Once the nail plate is removed, it can be soaked in betadine for later use if it is salvageable.

Once the nail plate is removed, incisions can be made perpendicular in the eponychium to be able to fully evaluate the nail bed (Fig. 3). The nail bed laceration can be repaired with either 6-0 absorbable suture (Fig. 4a) or with a polymerized tissue adhesive such as Dermabond (Singer et al. 2008; Quinn et al. 1997; Beam 2008). A randomized trial found no statistical difference in pain or functional ability between patients whose nail bed lacerations were repaired by Dermabond versus sutures (Beam 2008). The Dermabond can be applied in a light layer once the matrix is approximated and a sterile dressing should be applied for 7–10 days (Ramirez and Means 2011). In order to prevent a synechia, the eponychial fold should be splinted with the native nail or a nonbiologic stent (Fig. 4b) (Tosti 2018; Bharathi and Bajantri 2011). If the nail is not salvageable or if there is a complete avulsion with loss of the nail plate, flexible polypropylene foil (such as from a chronic wrapper), non-adherent gauze, or polyurethane sponge can be utilized (Tos et al. 2012).

A salve, such as triple antibiotic or Neosporin, can be used, which will allow easier facilitation of dressing removal at the first clinic appointment. In younger children, a cast should be utilized to protect the nail bed repair. In older patients, a bulky splint can be placed. Alumifoam splints are not sufficiently protective.

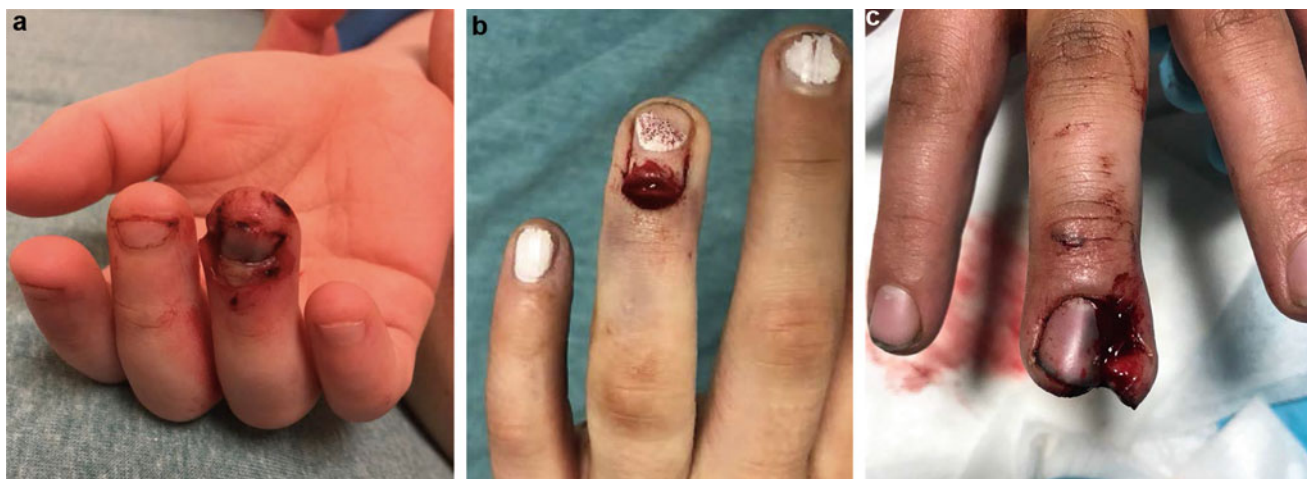


Fig. 2 (a) This is an example of a subungual hematoma, which does not necessarily require nail plate removal. However, no one would ever be faulted for proceeding with nail plate removal and evaluation of the matrix. (b) 12-year-old female with the nail plate resting superficial to the eponychium. This nail plate should be removed and the nailbed inspected for need for possible repair. This clinical picture is often seen

with Seymour fractures. (c) This is an example of an open wound from hedge trimmers to the nondominant long finger, resulting in trauma to the eponychium, nail plate, and nail bed. In this case, the nail plate should be removed to assess the injury to the nailbed and to repair the injuries



Fig. 3 Incisions are made perpendicular in the eponychium to fully evaluate the nail bed

5 Basic Principles

The nail should be removed carefully in order to prevent further damage to the matrix. When suturing the nail bed, knots should be placed at a distance sufficient enough to avoid tension (Tos et al. 2012). The extent of the injury reflects the prognosis, with more traumatic injuries and those that span the entire nail bed tending to have worse prognoses.

6 Images During Treatment

See Figs. 2–6.

7 Technical Pearls

It is sometimes difficult to repair the matrix and therefore simply approximating the matrix and placing a small amount of Dermabond is sufficient. It is important not to replace the nail plate or nail substitute until the Dermabond is completely dry. In younger children, a cast should be placed in order to protect the repair. If a portion of the nail bed is attached to the avulsed nail, it can be replaced as a composite free graft. In cases of subungual hematomas in patients experiencing significant pain, nail plate removal or trephination can be

Fig. 4 The nail bed laceration (a) is repaired with 6-0 chromic suture. Because the nail plate was not salvageable, the foil from the chromic suture wrapper is cut and utilized to place under the eponychium to prevent a synchia (b)

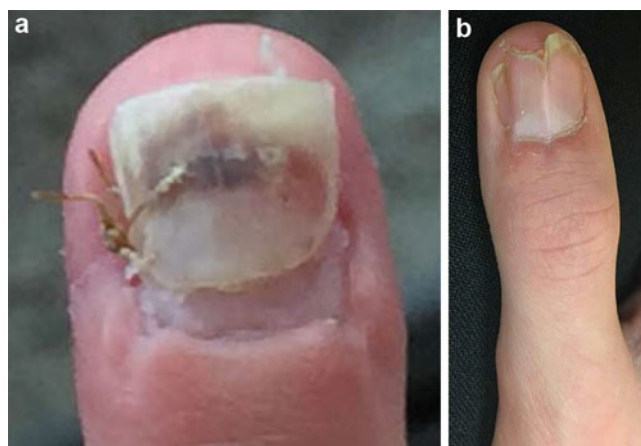
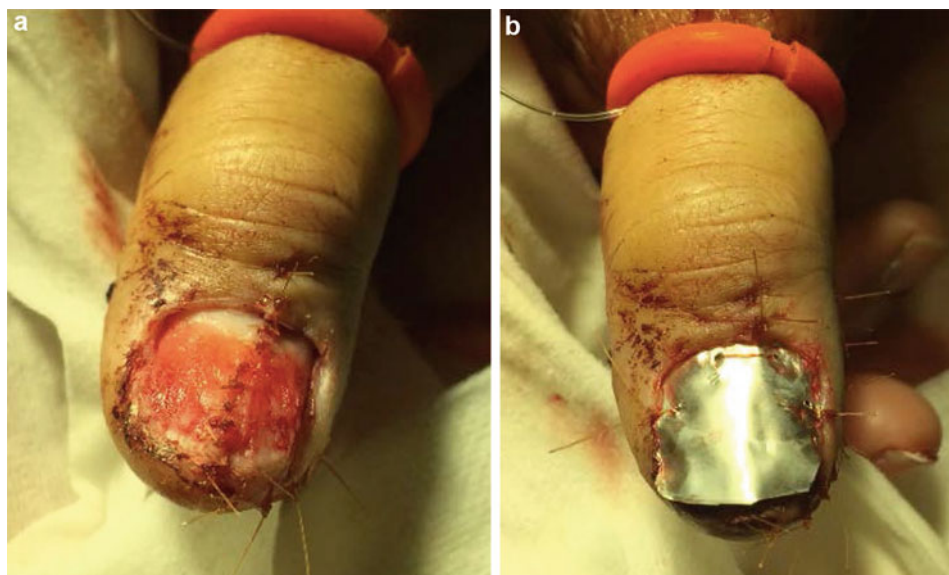


Fig. 5 (a) Appearance of nail growth after a nailbed repair. Patients should be counseled that the nail plate will eventually fall off. (b) Example of nail deformity

beneficial. However, it is important to avoid damaging the nail bed in the process (Ramirez and Means 2011).

8 Outcome Clinical Photos

Examples of nail plate outcomes are seen in Fig. 5. Figure 5a demonstrates the appearance as the nail plate, which was utilized as a stent, mobilizes outward with time, when the new nail plate begins to grow. Figure 5b demonstrates nail deformity, which can occur with nail bed injuries.

9 Avoiding and Managing Problems

Nail beds are important for proper nail growth, and injury can lead to deformities in the nail plate. Nail bed repairs begin to heal within 2 weeks, during which time it should be protected with a splint or cast (Bharathi and Bajantri 2011). The function and recovery prognosis of the nail will not be known until about two to three growth cycles (Ramirez and Means 2011). The nail can take between 3 and 5 months to completely grow to normal size and shape (Ramirez and Means 2011).

Although scar and deformity occurs due to the nature of the injury, careful suture may minimize the extent of deformity. Scarring on the dorsal roof can cause an opaque streak; scarring of the germinal matrix leads to a halt in growth or a split; and scarring of the sterile matrix can cause a split or detachment distal to the injury site (Tos et al. 2012). Prevention of the eponychial fold from adhering to the matrix can help prevent abnormal nail growth and synchia.

In order to replace an area of nail bed loss, a split-thickness nail bed graft from an adjacent nail bed can be utilized. If the patient requires a larger graft, the great toe nail bed can be used. However, there is ample morbidity that can occur with grafting, and this decision should be made with care.

If there is loss of the distal nail bed or if there is exposed bone, it can be covered with a local V-Y advancement flap. A nail bed graft can then be placed on the advancing edge of the flap. Split nails can be treated with removal of the nail and grafting or repair of the nail bed to remove scarring (Bharathi

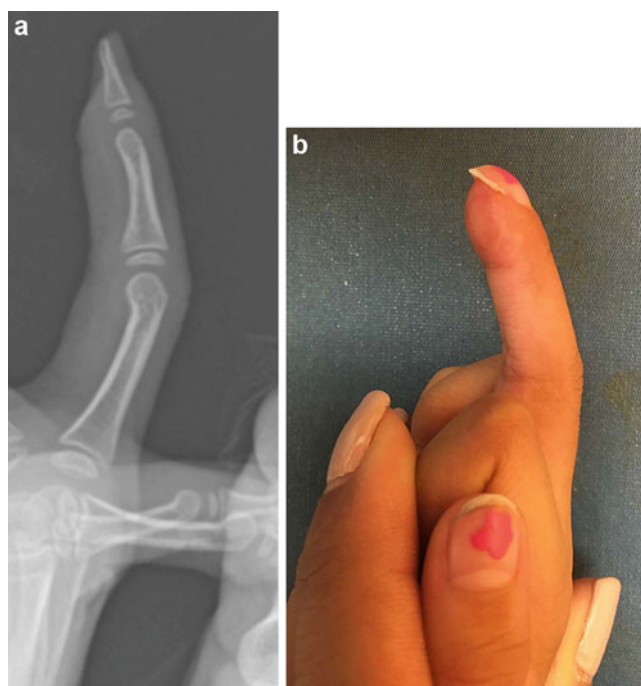


Fig. 6 Original radiographs (a), which demonstrate loss of the pulp but no actual nailbed deformity. Clinical picture (b) several months after the original injury, with a hook nail deformity

and Bajantri 2011). Hook deformity can be caused by the loss of the distal phalanx, which is required for proper nail growth. In order to prevent hook deformity, providers can reconstruct the hyponychium at the original injury (Tos et al. 2012). In cases of fingertip amputations with exposed bone, it is important not to trim the bone beyond the edge of the

matrix. Without the bone, the matrix will have no support, leading to potential hook deformity (Fig. 6) (Kumar and Satku 1993).

10 Cross-References

- Distal Fingertip Amputations: Local Wound Care
- Intra-articular Phalanx Fracture of Great Toe
- Metacarpophalangeal and Interphalangeal Joint Dislocation
- Phalangeal Shaft Fractures

References and Suggested Reading

- Beam JW (2008) Tissue adhesives for simple traumatic lacerations. *J Athl Train* 43(2):222–224. <https://doi.org/10.4085/1062-6050-43.2.222>
- Bharathi RR, Bajantri B (2011) Nail bed injuries and deformities of nail. *Indian J Plast Surg* 44:197–202
- Kumar VP, Satku K (1993) Treatment and prevention of “Hook nail” deformity with anatomic correlation. *J Hand Surg Am* 18(4):617–620
- Pencle F, Waseem M (2019) Fingertip injuries. *StatPearls*, Treasure Island
- Quinn J, Wells G, Sutcliffe T, Jarmuske M et al (1997) A randomized trial comparing octylcyanoacrylate tissue adhesive and sutures in the management of lacerations. *JAMA* 277(19):1527–1530
- Ramirez MA, Means KR Jr (2011) Digital soft tissue trauma: a concise primer of soft tissue reconstruction of traumatic hand injuries. *Iowa Orthop J* 31:110–120
- Singer AJ, Perry LC, Allen RL Jr (2008) In vivo study of wound bursting strength and compliance of topical skin adhesives. *Acad Emerg Med* 15(12):1290–1294
- Tos P, Titolo P, Chirila NL, Catalano F, Artiaco S (2012) Surgical treatment of acute fingernail injuries. *J Orthop Traumatol* 13:57–62
- Tosti A (2018) Nail disorders. Elsevier, St. Louis, Missouri

Compartment Syndrome of the Hand

Julie Balch Samora

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Abstract

Compartment syndrome is one of the few true orthopedic emergencies. It requires a high level of clinical suspicion, particularly in the pediatric population. Compartment syndrome is defined as an increase in intracompartmental pressure leading to a decrease in perfusion pressure causing tissue hypoxemia. Inadequate treatment or the missed diagnosis of compartment syndrome can lead to significant morbidity, such as nerve dysfunction, muscle contractures, loss of limb, rhabdomyolysis, chronic pain, and even mortality. Emergent fasciotomies are indicated, and often multiple surgeries are required. Postoperative rehabilitation is of paramount importance to help regain function.

1 Brief Clinical History

A 10-year-old male sustained a crush injury to his left hand by a front loader (a large piece of farm equipment). He presented in a delayed fashion 3 days after injury after initial management by another orthopedic surgeon, who had scheduled semi-elective surgical stabilization of his multiple metacarpal fractures later in that week. When the provider evaluated the patient in clinic 3 days after the injury, he was concerned for compartment syndrome and emergently sent him to our institution's emergency department for evaluation and management.

On exam, the patient was clearly uncomfortable. His hand was diffusely edematous with minimally compressible compartments. A large fracture blister was noted dorsally, and small fracture blisters were forming volarly. He held his hand in intrinsic minus position. He had pain with passive stretch of his fingers and altered sensation of the index, long, and ring fingers. He could actively slightly move his digits, but all motion was painful.

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2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

Suspected compartment syndrome of the hand
Multiple fractures of the hand metacarpals
Fracture blisters

4 Treatment Strategy

Delays in surgical treatment of compartment syndrome can result in permanent disability. There is a long-held belief that one should proceed with fasciotomies within 6–12 h or there may be more harm due to the risk of systemic effects of seeding the bloodstream due to manipulation and debridement of bacterial-laden necrotic muscle (Ouellette and Kelly 1996). Notwithstanding, there have been some authors who found no correlation between the time from diagnosis to fasciotomy and final functional outcomes (Kanj et al. 2013; Bae et al. 2001). Certainly in the hand, many would argue to proceed with fasciotomies even in delayed fashion.

Fig. 1 Clinical photograph 1 day after injury. (a) Appearance of the hand 2 days later (b) with significant swelling, fracture blisters, and intrinsic minus position



Fig. 2 Anteroposterior (a) and lateral (b) radiographs demonstrating index, long, ring, and small metacarpal fractures as well as significant soft tissue swelling



Although this patient presented 3 days after injury, he still demonstrated muscle function, and it was unclear when his compartment syndrome actually began. He was indicated for emergent hand fasciotomies, carpal tunnel release, and possible surgical stabilization of his fractures. There are ten compartments in the hand: hypothenar, thenar, and adductor compartments; the four dorsal interosseous compartments; and the three volar interosseous compartments. Some argue that the fascial compartments of the fingers (bound by Cleland and Grayson ligaments) should be released as well, but this decision should be made on a case-by-case basis and was not indicated in this case.

The surgical plan was to proceed with fasciotomies, stabilize the fractures, and decide intraoperatively whether to proceed with primary closure versus return for repeat irrigation and debridement in 2 days.

5 Basic Principles

Compartment syndrome usually occurs as a consequence of a traumatic event but can occur in the absence of underlying fractures (McQueen et al. 2000). Thermal injuries, infections, constrictive dressings, surgical positioning, rhabdomyolysis, bleeding disorders, or extravasation of a fluid (e.g., iatrogenic intravenous infiltrate) can lead to acute compartment

syndrome. Compartment syndrome in the upper extremities of children is most commonly caused by supracondylar humerus fractures, intravenous infiltrates, crush injuries, and tight casts. One should maintain a high suspicion of upper-extremity compartment syndrome in patients presenting with a “floating elbow” or concomitant distal radius fractures with ipsilateral elbow fractures. In children, the traditional “5 P” mnemonic (pain, pallor, paresthesias, paralysis, and pulselessness) has been replaced by the three “A’s”: agitation, anxiety, and the increasing need for analgesic pain medication (Bae et al. 2001). If there is any question of the clinical diagnosis, intracompartmental pressures can be measured and the differential pressure (ΔP = diastolic blood pressure – intracompartmental pressure) determined to help guide treatment, with a normal differential of greater than or equal to 30 mmHg (Whitesides et al. 1975).

Irreversible changes can occur with ischemia more than 6 h and can lead to severe functional consequences. Volkmann’s contracture of the forearm leads to muscle fibrosis, decreased motion, reduced strength, and clawing of the fingers.

6 Images During Treatment

See Figs. 3, 4, 5, 6, 7, and 8.



Fig. 3 Two longitudinal dorsal incisions of the hand either between the index-long and ring-small intervals or immediately over the index and ring fingers enable release of all osteofascial envelopes. An incision directly over the index finger has the advantage in that this allows easy access to the first volar interosseous and adductor pollicis muscles via

blunt dissection along the radial aspect of the index metacarpal. Significant decompression of edema (a) with loose closure at initial surgery (b) to protect the open fractures. Pins were bent and cut and protected with Xeroform dressing

Fig. 4 AP (a) and lateral (b) radiographs taken intraoperatively demonstrating closed reduction of the ring and small metacarpal base fractures and percutaneous pinning of the index and long metacarpal fractures. The long metacarpal fracture was unstable, and placing the pin into the capitate increased stability without requiring further hardware

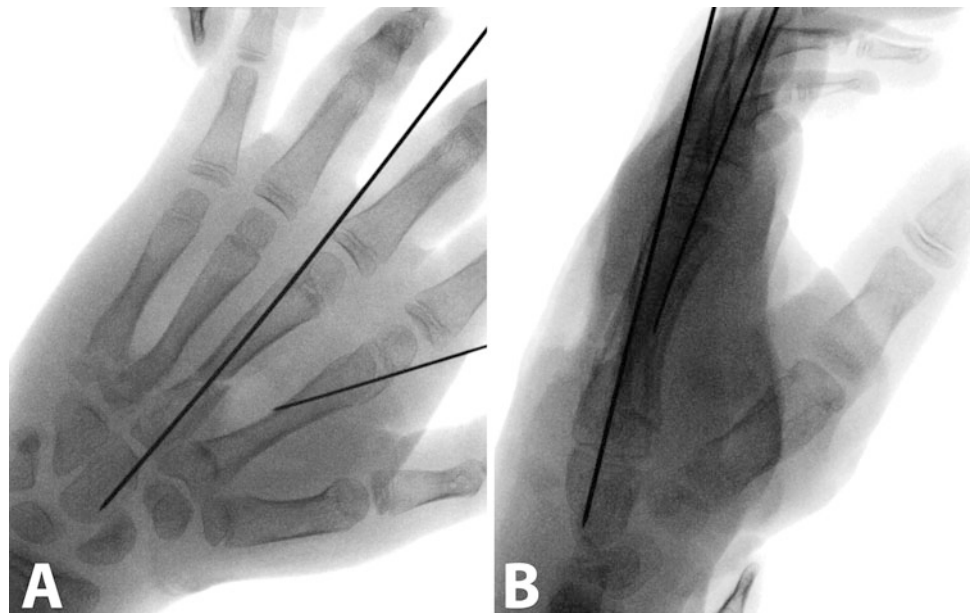


Fig. 5 Appearance of the hand (dorsal, A, and palmar, B) 2 weeks after surgery with well-healed incisions and significant improvement of swelling but still with an intrinsic minus resting position. On exam, he had present but altered sensation in all of his nerve distributions. He could palmarly abduct his thumb, extend and flex his thumb IP joint, but demonstrated minimal motion of his ulnar four digits due to severe pain and stiffness. He did have pain when the fingers were passively flexed. Therapy was initiated at this visit



7 Technical Pearls

The diagnosis of compartment syndrome in children is difficult and often delayed, and surgeons must maintain a high index of suspicion and keep in mind the three A's.

Multiple metacarpal fractures or a crush injury should heighten the possibility of compartment syndrome of the hand.

It is a difficult decision to primarily close wounds versus delaying the closure. These decisions depend on the mechanism of injury; the intraoperative findings,

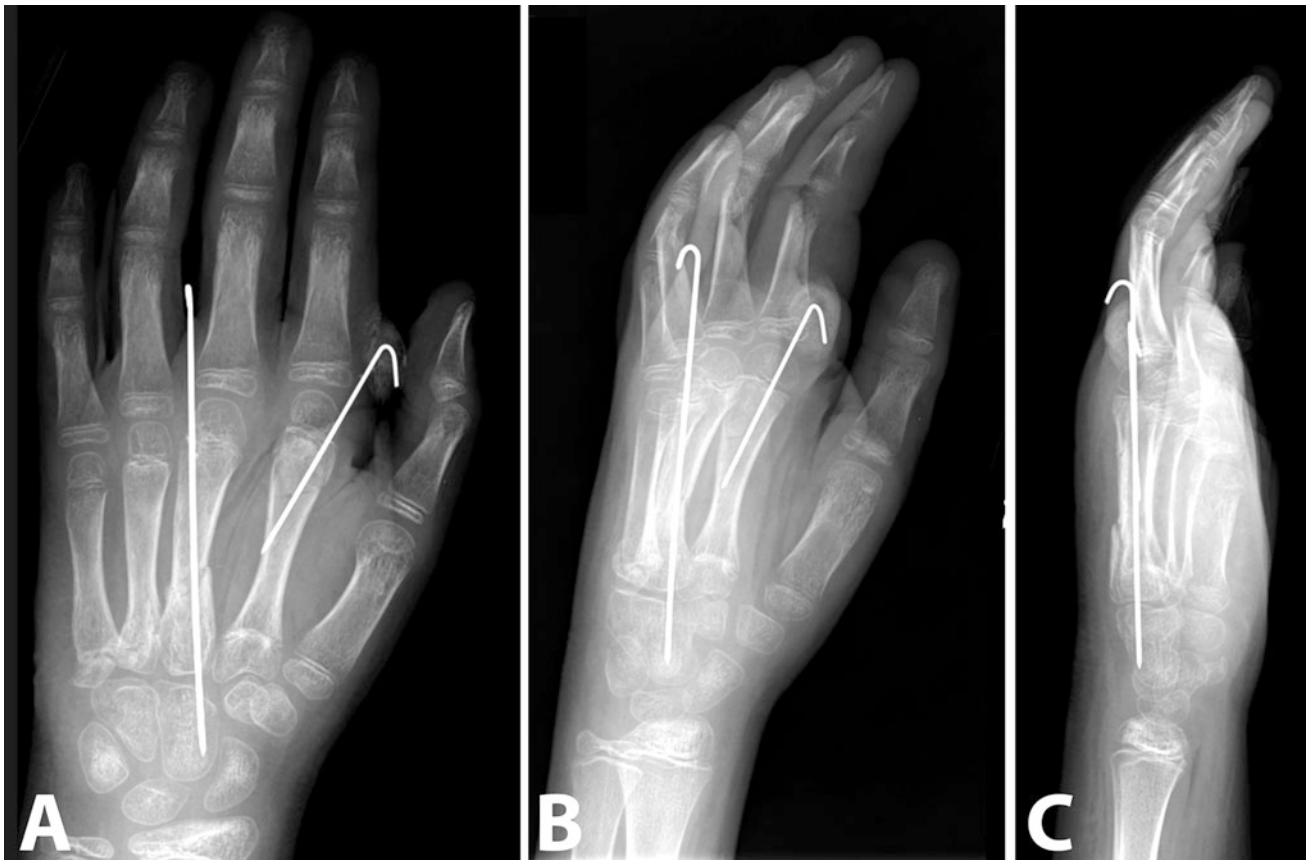


Fig. 6 At 6 weeks, healing of his fractures is demonstrated on radiographs and the pins were removed. Therapy including static and dynamic splinting was initiated, but he had difficulty with both passive

(PROM) and active range of motion (AROM) exercises due to extreme pain. He was referred to the pain team for consideration of a stellate ganglion block

whether there are fractures; and the overall clinical picture. If there is any uncertainty, the wound should be left open.

When muscle viability is a concern, a repeat irrigation and debridement should be performed every 48 h.

Vacuum-assisted wound closure (VAC) therapy remains an option to cover open wounds and has been shown to decrease hospital stays, reduce the need for skin grafting, and lead to a lower rate of infection.

After the surgery, maintain the hand in intrinsic plus position to help reduce contractures and improve function. A transarticular K-wire to pin the metacarpophalangeal joints in flexion may be helpful.

If compartment syndrome of the forearm occurs, there are many possible skin incisions that may be utilized to decompress the three compartments. The author's preferred volar incision is seen in Fig. 9a, which allows for a large flap to cover the median nerve. The carpal tunnel is

released, longitudinal veins are preserved and damage to cutaneous nerves is minimized, and decompression of both the superficial and deep compartments can be accomplished. Whereas some surgeons believe decompressing the carpal tunnel also releases the pressure in Guyon's canal, others believe both compartments should be individually released. In the anterior compartment, the superficial layer consists of the FCU, palmaris longus, FCR, and pronator teres; the intermediate layer includes the FDS; and the deep layer (which is most often affected) includes the FDP, FPL, and pronator quadratus muscles. The dorsal approach (Fig. 9b) can be a simple longitudinal incision to allow access to the mobile wad of Henry (brachioradialis, ECRL, and ECRB) and dorsal compartment (EDC, EDM, and ECU). VAC therapy is a good option in the setting of acute forearm compartment releases, with care to place a white sponge on any exposed nerves, tendons, or major arteries.

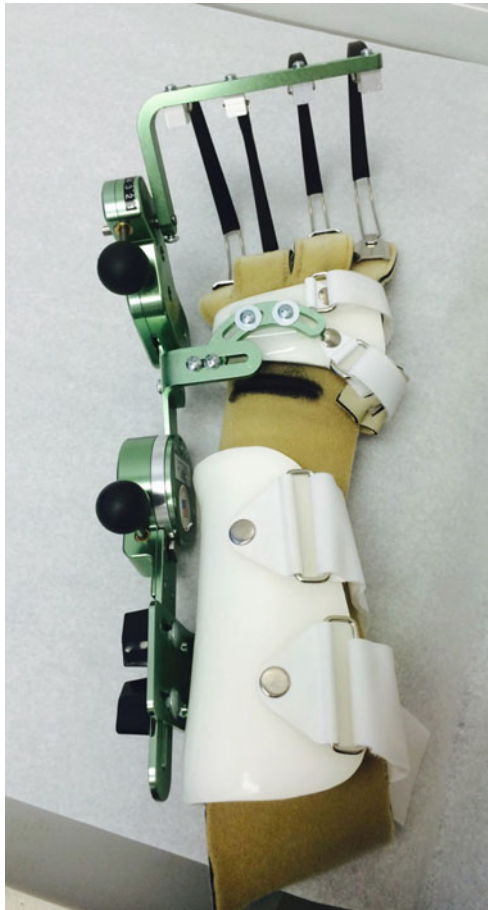


Fig. 7 Naprosyn, Neurontin, and oxycodone were prescribed by pain management. He did not have a stellate ganglion block. Hand continuous passive motion (CPM) therapy was initiated at 2 months. The CPM device is pictured above

8 Outcome Clinical Photos and Radiographs

See Fig. 10.

9 Avoiding and Managing Problems

Early diagnosis and intervention is key to prevent substantial morbidity.

The worst results occur in patients with severe crush injuries or arterial injury. In upper-extremity compartment syndrome, patients may develop a position of elbow flexion, forearm pronation, wrist flexion, thumb adduction, and intrinsic minus position. Contractures are categorized as mild, moderate, or severe (Tsuge 1975), with Volkmann's contracture being deemed as the latter, with extreme muscle necrosis. In these cases, poor function is assumed, but surgery entails debridement of all necrotic tissue, neurolyses of the median and ulnar nerves, and tenolyses. A flexor/pronator slide may help hand position, and tendon transfers can be a viable option for the less severe cases.

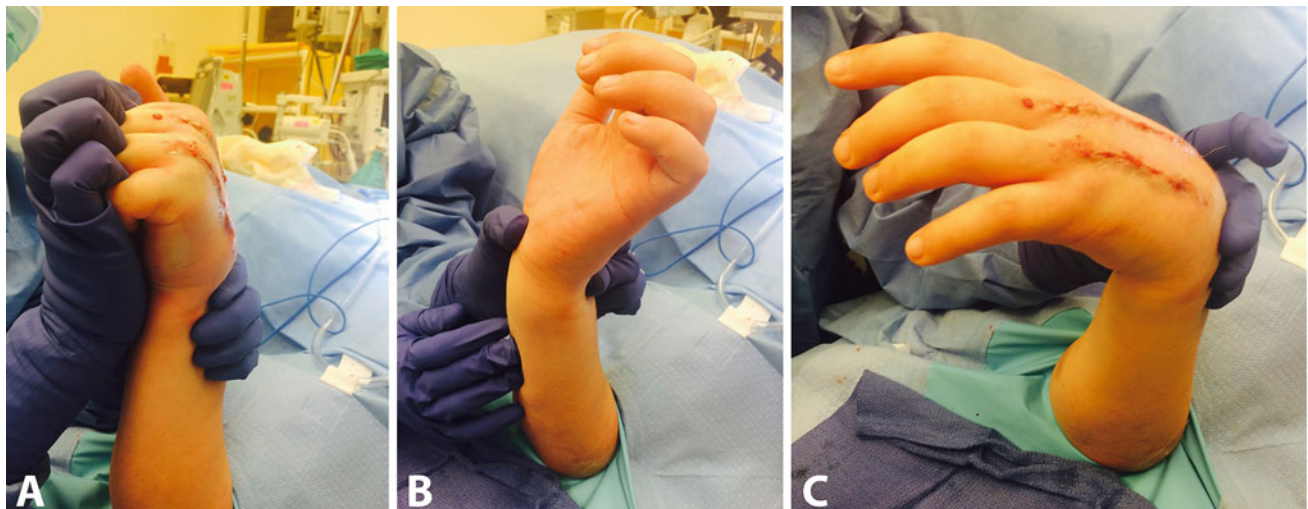


Fig. 8 At 3 months, a tenolysis was performed. Intraoperatively, full flexion at metacarpophalangeal joints was achieved (a). Good tenodesis was observed with good gliding of extensor tendons (b, c). Aggressive AROM and PROM are initiated postoperative day 1

Fig. 9 Volar (a) and dorsal (b) skin incisions for forearm compartment syndrome fasciotomies

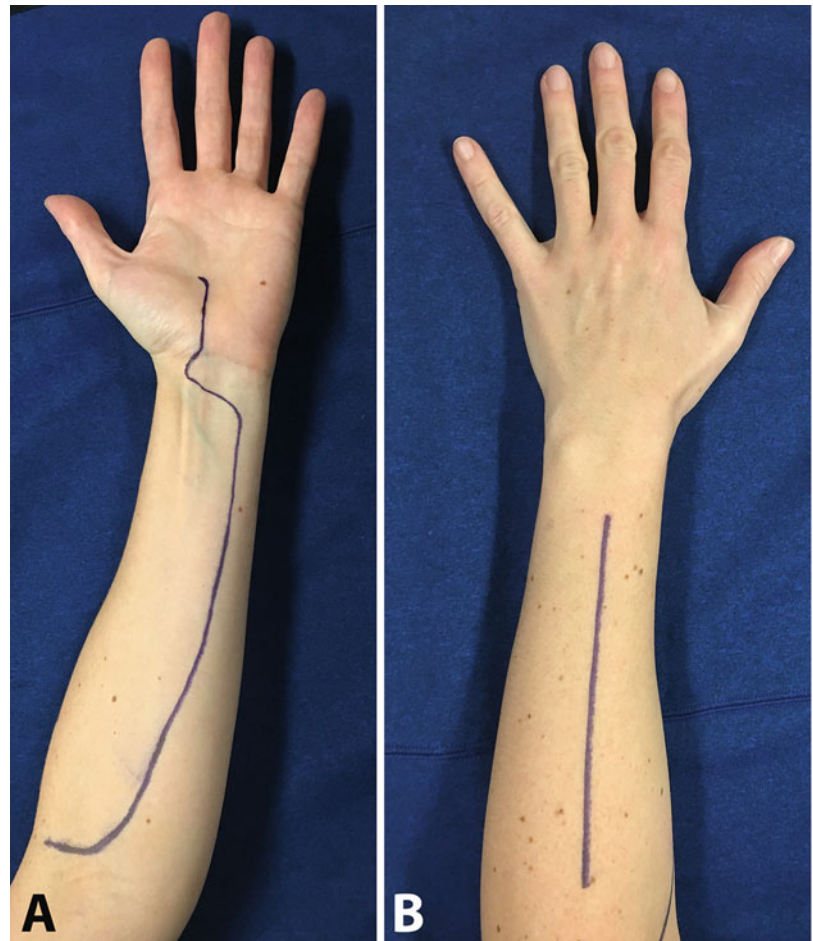
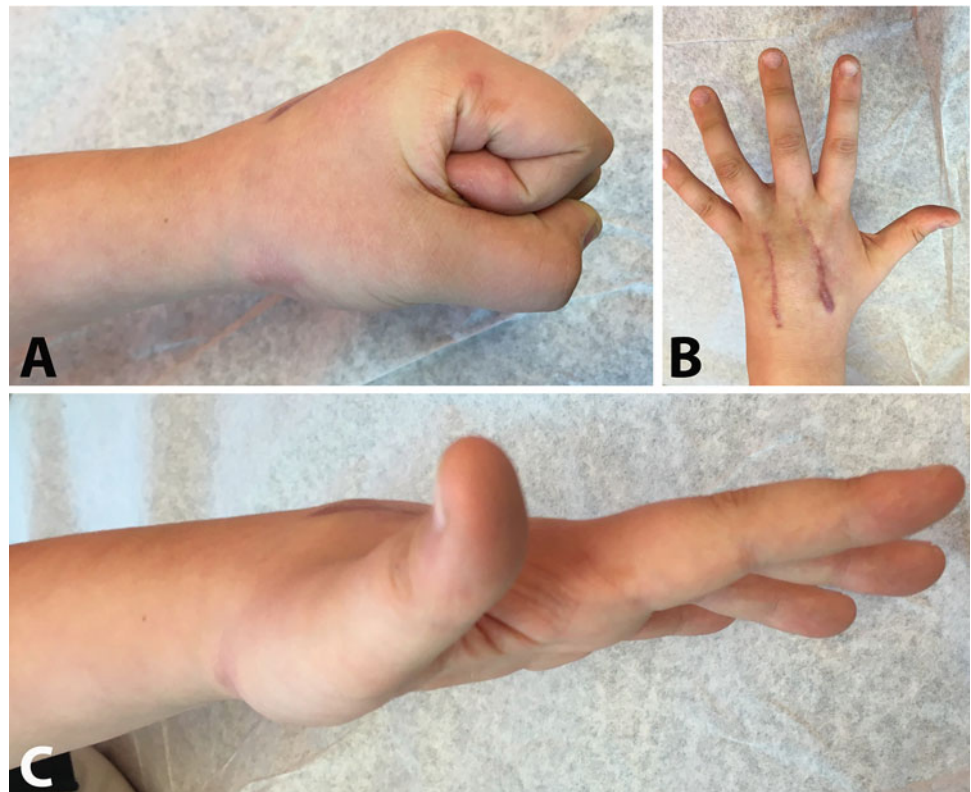


Fig. 10 At a little more than 5 months after his surgery, the patient still had severe pain on a daily basis. A stellate ganglion block was performed by the pain service which was successful in eliminating his pain. He was able to regain full range of motion (a–c), discontinue all of his oral medications, and return to his 4-h activities and farm work



10 Cross-References

► [Compartment Syndrome of the Leg](#)

References and Suggested Readings

Bae DS, Kadiyala K, Waters PM (2001) Acute compartment syndrome in children: contemporary diagnosis, treatment and outcome. *JPO* 21:680–688

Kanj WW, Gunderson MA, Carrigan RB, Sankar WN (2013) Acute compartment syndrome of the upper extremity in children: diagnosis, management, and outcomes. *J Child Orthop* 7:225–233

McQueen MM, Gaston P, Court-Brown CM (2000) Acute compartment syndrome. Who is at risk? *J Bone Joint Surg Br* 82:200–203

Ouellette EA, Kelly R (1996) Compartment syndromes of the hand. *J Bone Joint Surg Am* 78:1515–1522

Tsuge K (1975) Treatment of established Volkmann's contracture. *J Bone Joint Surg Am* 57(7):925–929

Whitesides TE, Haney TC, Morimoto K, Harada H (1975) Tissue pressure measurements as a determinant for the need of fasciotomy. *Clin Orthop Relat Res* 113:43–51

Long Arm Cast

Julieanne P. Sees and Lucio Ricieri Perotti

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Abstract

A 7-year-old girl sustained a right forearm trauma after fall from a monkey bar. She was taken to the emergency room (ER) where she was diagnosed with a right radius and ulna midshaft fracture. After reduction of fracture, she was immobilized with a long arm cast for 6 weeks.

1 Brief Clinical History

The patient is a right-hand-dominant 7-year-old female who was seen in our emergency department after falling off the monkey bars at daycare. After an anteroposterior (AP) and lateral (LAT) radiographs, she was diagnosed with a proximal third radial and midshaft ulna fractures. Although AP view had shown good alignment, the LAT view showed

30 degrees and 25 degrees of dorsal angular deformity in radius and ulna, respectively, (Fig. 1). She was neurovascularly intact and able to extend and flex all fingers. Under fluoroscopy the fracture was reduced and immobilized by long arm cast (Fig. 2). AP and LAT radiographs were reviewed. LAT radiograph showed radius and ulna shaft fractures with acceptable alignment 18 and 5 degrees, respectively (Fig. 3). Weekly radiographs were reviewed for the first 3 weeks (Fig. 4), then at 6 weeks after injury, forearm AP and LAT radiographs were obtained out of cast showing acceptable alignment (Fig. 5a, b). After 9 months she recovered pronation and supination, both 80 degrees of range of motion (Fig. 5e, f).

2 Preoperative Clinical Photos and Radiographs

See Fig. 1

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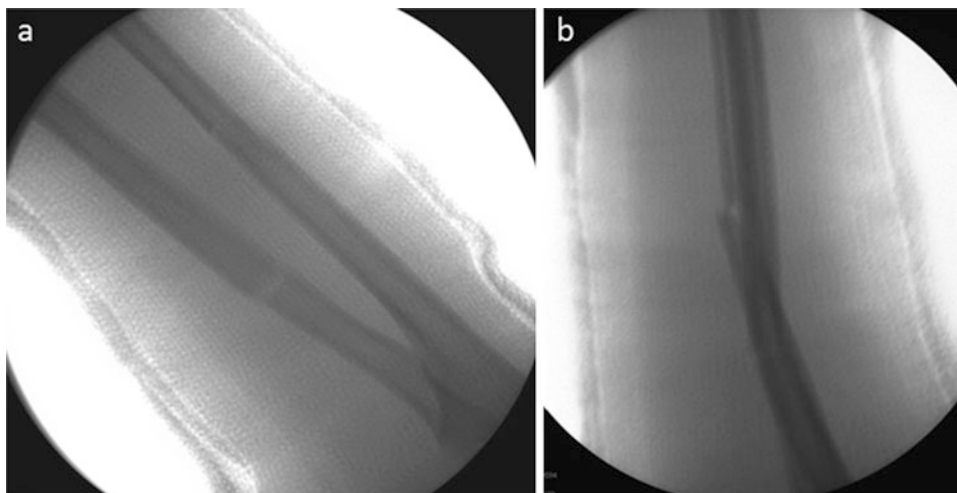
3 Preoperative Problem List

1. Proximal third radius and ulna shaft fractures
2. Dorsal deviation and rotation of forearm bones
3. Restore alignment of forearm bones



Fig. 1 (a) AP and (b) LAT radiographs of forearm show radius and ulna shaft fractures

Fig. 2 (a) AP and (b) LAT views under fluoroscopy after reduction of radius and ulna fractures



4 Treatment Strategy

The goal of forearm fracture treatment is appropriate to restore the length, rotation, and alignment to allow normal function after healing and remodeling of bones (Pace 2016). Radiographic follow-up must be evaluated every week in the first 3 weeks after reduction. Long arm cast provides a good immobilization in forearm fractures in children after reduction.

5 Basic Principles

Closed reduction and casting still is the *gold standard* for forearm pediatric fractures (Jones and Weiner 1999). The manipulation and reduction of forearm fractures in children can be achieved under conscious sedation. It is important to reconstitute the alignment of radius and ulna. Cast immobilization thereby is used with three-point molding, adequate padding, and enough casting material (Vopat et al. 2014). Three-point molding entails reducing the fractures, applying the cast, and then molding pressure at the site of fracture and proximal/distal to the fracture creating three-point fixation. Cast index, defined as the ratio of sagittal to coronal width of cast, has been shown to be important in predicting successful closed management (Fig. 3) (Kamat et al. 2012). Loss of reduction is associated with poor cast molding (a higher cast index) (Webb et al. 2006).

6 Images During Treatment

See Figs. 2 and 3

7 Technical Pearls

1. Reduction under conscious sedation helps in molding the cast. Example of three-point molding technique is



Fig. 3 (a) AP and (b) LAT radiographic views after fracture reduction. White lines show a (a) coronal and (b) sagittal width of cast

when the distal fracture fragments are tipped dorsally, the apex is volar, one could hold her left hand flat palm at the apex of the fracture, the right hand push the distal fragments into alignment, and use a knee or another set of hands to stabilize the lateral elbow in a three points of fixation mold.

2. Greenstick fractures must be molded in three-point molding cast technique.
3. Cast index is a good parameter after casting in greenstick forearm and complete both bone fractures (radius and ulna).
4. Upon evidence of callus formation, long arm cast may be changed at week 3 or week 4 after initial reduction and casting.

8 Outcome Clinical Photos and Radiographs

See Figs. 4 and 5

9 Avoiding and Managing Problems

1. If reduction of the fractures to restore alignment and to correct malrotation and deviation is necessary, conscious sedation can improve cast molding after reduction.
2. Fluoroscopy (mini C-arm) improves the quality of reduction, reduces radiation exposure, and reduces the need for secondary procedures.



Fig. 4 After 1 week (a, b) radiograph follow-up show no loss of reduction. Second (c, d) and third week (e, f) of radiographic follow-up show an acceptable alignment and osseous callus formation (e, f)



Fig. 5 (a, b) 6 weeks, (c, d) 10 weeks, and (e, f) 9 months after reduction show healing of fracture with remodeling of dorsal deviation

3. Proper molding of the cast is essential to successful management of forearm fractures.
4. Casts that are univalved or bivalved too aggressively may run a higher risk of loss of reduction.
5. The patient is observed in ER after sedation for signs of neurovascular compromise.
6. The patient is discharged with instruction for strict elevation and warning signs of compartment syndrome.
7. Instructions before discharge on cast care includes keeping the cast clean dry and avoiding insertion of objects such as sticks or coins down inside the cast.
8. Weekly follow-up in first 3 weeks is important to maintain correction and alignment while providing opportunity for cast adjustments should there be a need.

10 Cross-References

- [Munster Cast](#)
- [Short Arm Cast](#)

Reference and Suggested Readings

- Jones K, Weiner DS (1999) The management of forearm fractures in children: a plea for conservatism. *J Pediatr Orthop* 19(6):811–815
- Kamat AS, Pierse N, Devane P, Mutimer J, Horne G (2012) Redefining the cast index: the optimum technique to reduce redisplacement in pediatric distal forearm fractures. *J Pediatr Orthop* 32(8):787–791
- Pace JL (2016) Pediatric and adolescent forearm fractures: current controversies and treatment recommendations. *J Am Acad Orthop Surg* 24(11):780–788
- Vopat ML, Kane PM, Christino MA, Truntzer J, McClure P, Katarincic J, Vopat BG (2014) Treatment of diaphyseal forearm fractures in children. *Orthop Rev* 6(2):5325
- Webb GR, Galpin RD, Armstrong DG (2006) Comparison of short and long arm plaster casts for displaced fractures in the distal third of the forearm in children. *J Bone Joint Surg Am* 88(1):9–17

Munster Cast

Julianne P. Sees and Lucio Ricieri Perotti

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Abstract

An 8-year-old boy presents with right forearm pain after a fall during gym class onto his right arm. He was taken to the emergency room (ER) and was diagnosed with midshaft forearm fracture of the radius with angular deformity of the right forearm. After reduction of the fracture, the child was immobilized with a long arm cast for 3 weeks and then transitioned to a munster cast for an additional 3 weeks. He went on to uneventfully heal his fracture.

1 Brief Clinical History

An 8-year-old right-hand-dominant male presented to our emergency department after falling onto his right arm after tripping in gym class. The patient was noted to be

neurovascularly intact. Radiographs revealed an angulated midshaft radius fracture in his right forearm. After anteroposterior (AP) and lateral (LAT) radiographs of his forearm, he was diagnosed with a 20 degrees apex volar midshaft radius fracture in need of manipulation (Fig. 1). Under fluoroscopy the fracture was reduced and immobilized by long arm cast where AP and LAT radiographs showed reduction of fracture (Fig. 2). The subsequent radiographs were taken at 10 days postreduction showing maintained position (Fig. 3a, b). At 3 weeks postreduction, AP and LAT radiographs showed anatomical alignment and adequate callus healing (Fig. 3c, d). Subsequently the long arm cast was removed and replaced with a munster cast for 3 weeks further which allowed elbow flexion and extension while limiting pronation and supination of the forearm (Fig. 3e). After 6 weeks postreduction, clinical examination showed no tenderness in his forearm with radiographs out of the cast demonstrated well-healed forearm (Fig. 4); thus he was allowed of active range of motion with no restrictions.

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2 Preoperative Clinical Photos and Radiographs

See Fig. 1

3 Preoperative Problem List

1. Midshaft radius fracture with mild angular displacement. Successful fracture reduction and initial treatment in a long arm cast
2. Transition to a munster cast for control of supination/pronation of the forearm while allowing elbow range of motion

4 Treatment Strategy

Forearm fracture treatment is appropriate to restore appropriate length, rotation, and alignment and to allow for normal function after healing and remodeling of the bones. Many fractures are amenable to closed reduction and in the emergency room and allows an anatomical reduction. There is no consensus about length of time in long arm cast for both bone forearm fractures in children, particularly with relation to forearm rotational control. Transition to a munster cast allows continued pronosupination control while allowing for elbow range of motion.

5 Basic Principles

Closed reduction and casting still is the *gold standard* for forearm pediatric fractures (Jones and Weiner 1999). The manipulation and reduction of radius and ulna fractures in children can be achieved under conscious sedation and maintained without surgical intervention. It is important to reconstitute the alignment of both radius and ulna. Cast immobilization thereby is used with three-point molding, adequate padding, and enough casting material. To control forearm pronation and supination is important for healing forearm fractures with suggestion that long arm cast provides the greatest restriction to unwanted motion (Kim et al. 2012). However, the long arm cast offers forearm stability at the cost of elbow motion. Consequently, to investigate this, it has been shown biomechanically beneficial to use a munster cast when limiting forearm rotation is desired without strict elbow immobilization (Trosshia et al. 2012).

6 Images During Treatment

See Fig. 2

7 Technical Pearls

1. Evaluate the angular deformities closely, and the reduction will be applied in the opposite directions of these deformities.

Fig. 1 (a) AP and (b) LAT radiographs of right forearm show an angulated midshaft radius fracture and a nondisplaced ulna fracture

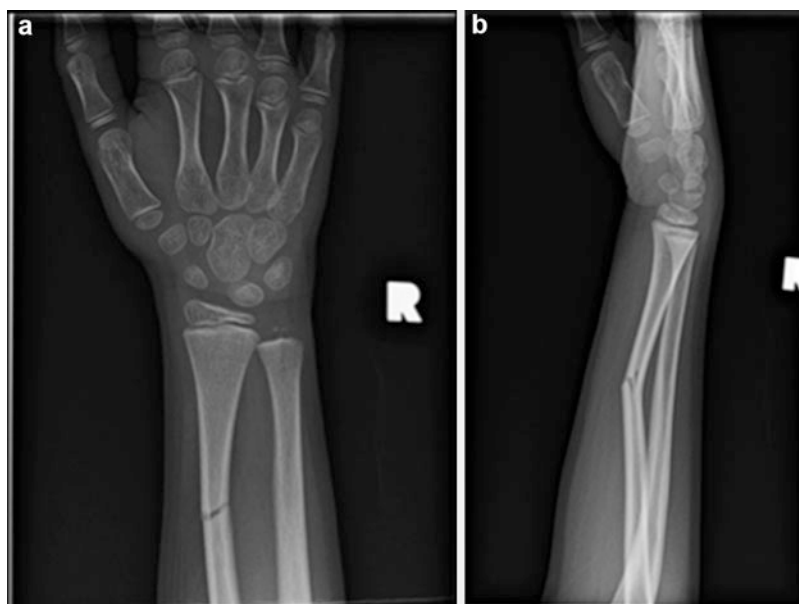




Fig. 2 (a) AP and (b) LAT radiographs from outside institution demonstrating midshaft radius fracture with angulation before reduction. (c) AP and (d) LAT confirm position of forearm after cast molding

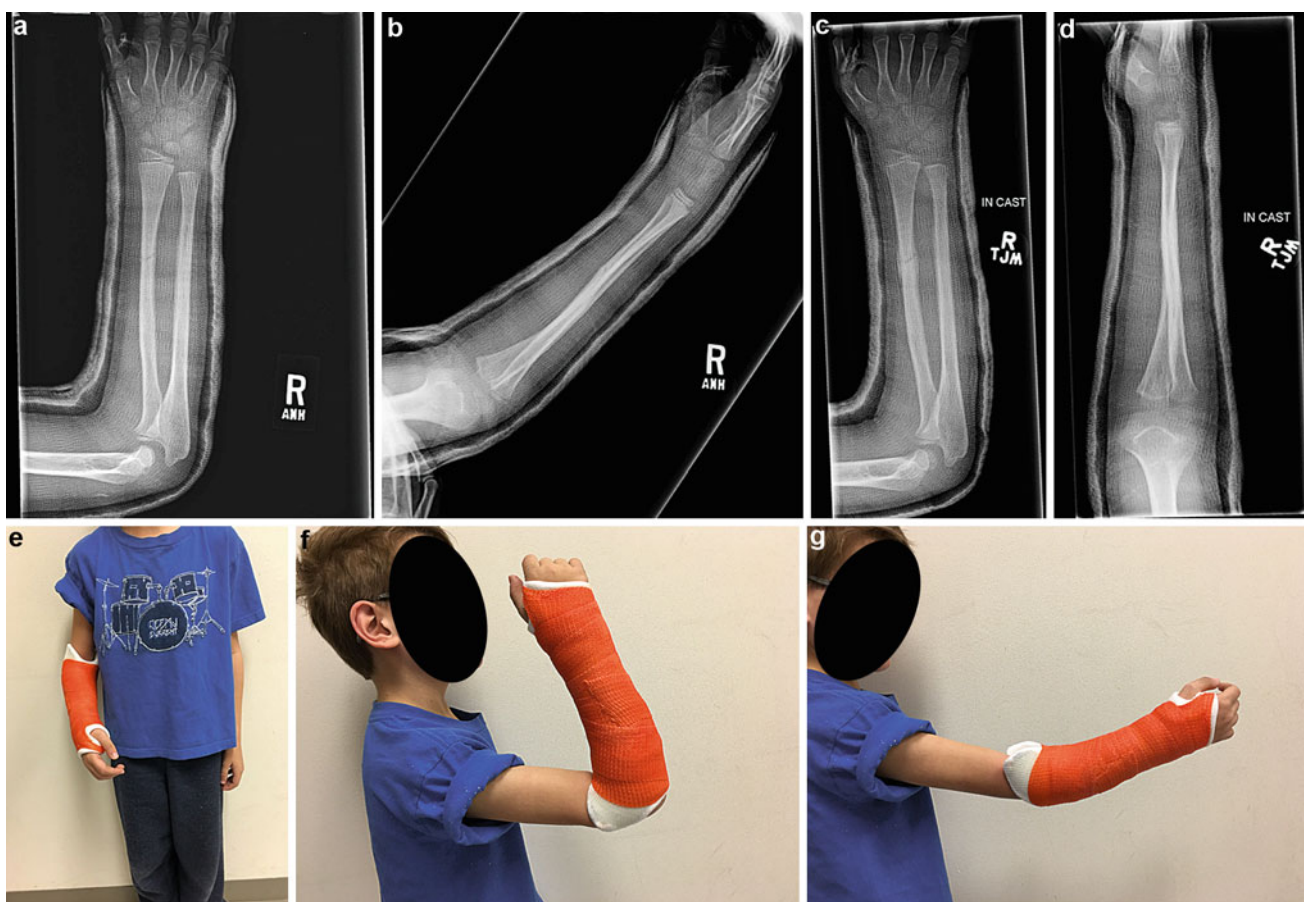


Fig. 3 Ten days after reduction, (a) AP and (b) LAT radiographs show good maintenance of anatomical reduction. Three weeks after the initial procedure, (c) AP and (d) LAT confirm the positioning has been

maintained with adequate callus formation, thus the child is switched at this time from long arm cast to munster cast (e–g). The cast limits pronosupination while allowing elbow range of motion

Fig. 4 Radiographs (a, b) after munster cast was removed show a well-healed forearm



2. Conscious sedation and fluoroscopy guide are helpful for an anatomical reduction.
3. Munster cast is placed from the distal palmar crease of the metacarpophalangeal joints to 1 inch distal to the cubitus of the finger side and 3 inches proximal to the olecranon. The cast must be well applied using molding cast technique with detection of evidence of callus formation and allow for complete elbow flexion and extension while restricting rotation of the forearm.
2. Fluoroscopy (mini C-arm) improves the quality of reduction, reduces radiation exposure, and reduces the need for secondary procedures.
3. Proper molding of the cast is essential to successful management of forearm fractures.
4. The patient is discharged with instruction for strict elevation and warning signs of compartment syndrome.
5. Instruction before discharge on cast care includes keeping the cast clean and dry and avoiding insertion of objects such as sticks or coins down inside the cast.
6. Follow-up must be done no later than 10 days, to evaluate any displacement or need for adjustment or manipulation.
7. If healing is adequate, transition from long arm cast to munster cast provides forearm motion control while allowing for earlier elbow motion to avoid stiffness.

8 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4

9 Avoiding and Managing Problems

1. If reduction of the fractures to restore alignment and to correct malrotation and deviation is necessary, conscious sedation can improve cast molding after reduction.

10 Cross-References

- Long Arm Cast
- Short Arm Cast

References and Suggested Readings

- Jones K, Weiner DS (1999) The management of forearm fractures in children: a plea for conservatism. *J Pediatr Orthop* 19(6):811–815
- Kim JK, Kook SH, Kim YK (2012) Comparison of forearm rotation allowed by different types of upper extremity immobilization. *J Bone Joint Surg Am* 94(5):455–460
- Trossia AM, Elfar JC, Hammert WC (2012) Biomechanical measurements of forearm pronosupination with common methods of immobilization. *J Hand Surg Am* 37(5):989–994

Short Arm Cast

Julieanne P. Sees and Lucio Ricieri Perotti

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Abstract

A 9-year-old boy sustained a right forearm trauma after a fall from a hoverboard. He was taken to the emergency room (ER) and was diagnosed with a right distal radius physeal fracture. After reduction of fracture, the child was immobilized with a short arm cast for 4 weeks.

1 Brief Clinical History

The patient is a right-hand dominant 9-year-old male who was seen in our ER after falling off the hoverboard. He was taken to the ER with pain and dorsal angular deformity in his distal right forearm. After anteroposterior (AP) and lateral (LAT) radiographs of his forearm, he was diagnosed with a Salter-Harris type II fracture on the right distal radius. AP

radiograph shows 25° of radial deviation. LAT radiograph shows a complete dislocation of epiphysis from metaphysis (100%) and 45° of dorsal angular deviation (Fig. 1). The patient was neurovascularly intact and able to extend and flex all fingers. Under fluoroscopy the fracture was reduced and immobilized by short arm cast (Fig. 2). AP and LAT radiographs were reviewed. They showed reduction of physeal fracture and restoration of wrist alignment (Fig. 3). Cast index (CI: x/y) confirms a good cast molding (Fig. 4). The control radiographs were taken at 4 and 12 days post-reduction (Fig. 5). At 4 weeks postreduction, forearm AP and LAT radiographs were obtained showing anatomical alignment (Fig. 6a and b). Subsequently the cast was removed. At this point, clinical examination showed no tenderness in his distal radius. Immobilization brace was prescribed for 2 weeks, allowance of active range of motion and no restrictions from activities. Nine months later distal radius radiographs showed a healed fracture (Fig. 6c and d) with no signs of distal radius growth arrest (Fig. 7).

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Fig. 1 (a) AP and (b) LAT radiographs of the right forearm show a complete displaced distal radius physeal fracture (Salter-Harris type II) and a dorsal angular deformity of his wrist

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Distal radius physeal fracture (Salter-Harris type II) with complete displacement
2. Dorsal and radial angular deformities of the wrist
3. Successful fracture reduction without additional damage to the growing physis

4 Treatment Strategy

Forearm fracture treatment is appropriate to restore the length, rotation, and alignment and to allow for normal wrist function after healing and remodeling of the bones. Conscious sedation and fluoroscopy can be done in the ER and allow an anatomical reduction with minimal damage in the physis. After reduction, follow-up radiographs of displaced physeal fractures must be taken no later than 5–7 days to evaluate maintained alignment and reduction. After that period, the risk of growth arrest increases if there is a need for remanipulation of site fracture. There is no consensus about long or short arm casts in distal radius fracture in children. Short arm cast seems to provide a good stabilization of the fracture when molding is applied and cast index (CI) is ≤ 8 (Webb et al. 2006; Kamat et al. 2012).

5 Basic Principles

Closed reduction and casting still is the *gold standard* for forearm pediatric fractures (Jones and Weiner 1999). The manipulation and reduction of distal radius and ulna fractures in children can be achieved under conscious sedation. It is important to reconstitute the alignment of radius and ulna. Cast immobilization thereby is used with 3-point molding, adequate padding, and enough casting material (Vopat et al. 2014). Cast index, defined as the ratio of sagittal to coronal width of cast (Fig. 4), has been proven important in predicting successful closed management (Fig. 3) (Kamat et al. 2012). Loss of reduction in distal radius fracture in children is associated with displaced fractures, nonanatomical reduction, and poor cast molding (a higher cast index; $CI > 8$) (Asadollahi et al. 2015; Webb et al. 2006).

6 Images During Treatment

See Figs. 2, 3, and 4.

7 Technical Pearls

1. Evaluate the angular deformities closely, and the reduction will be applied in the opposite directions of these deformities.

Fig. 2 (a) AP and (b) LAT fluoroscopy after a reduction of displaced distal radius physeal fracture show an anatomical reduction. (c) AP and (d) LAT confirm position of epiphysis after cast molding

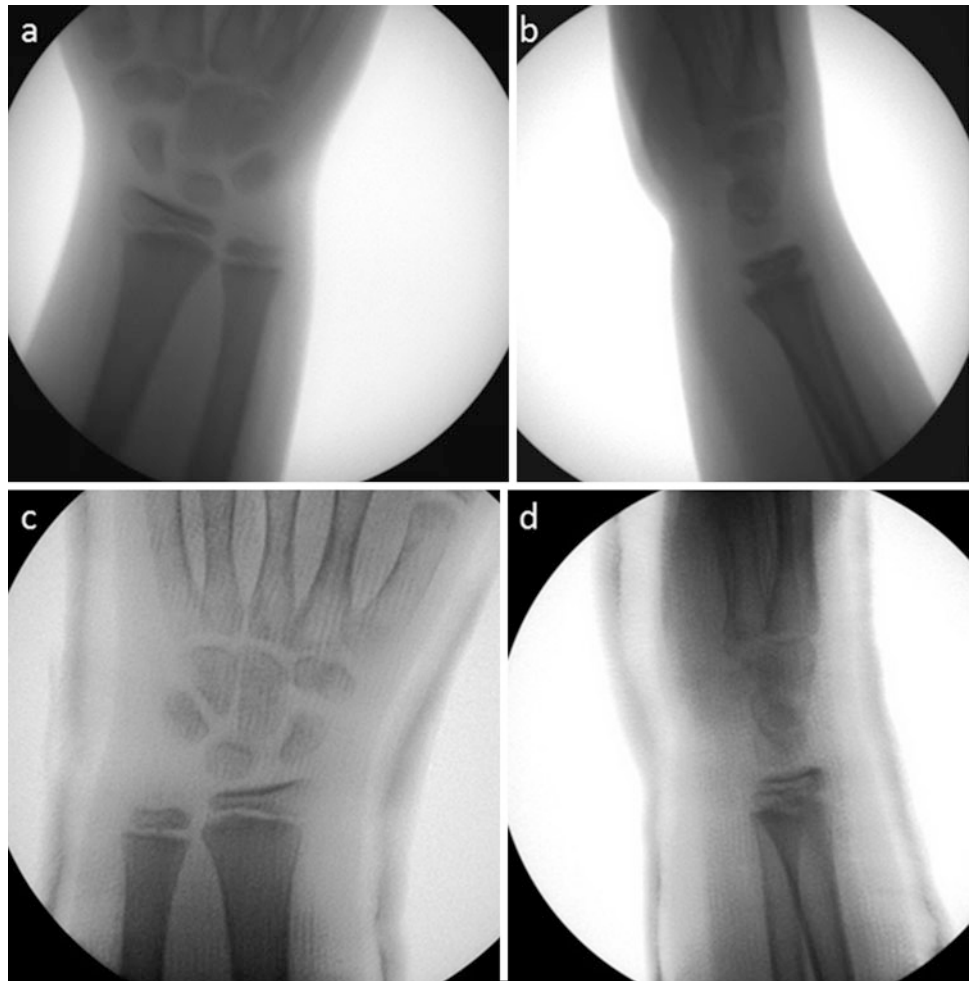


Fig. 3 (a) AP and (b) LAT radiographs of the wrist confirm the anatomical reduction after cast molding



Fig. 4 (a) Coronal and (b) sagittal lines of cast index ($CI = x/y$; $CI \leq 8$)



2. Conscious sedation and fluoroscopy guide are helpful for an anatomical reduction.
3. Traction before reduction to stretch the muscles may help and decrease further damage to the physis.
4. Reduction must be done in a unique and precise movement (Technical Pearl 1).
5. Short arm cast must be placed after reduction of first place stockinette to extend beyond fingers and elbow, making sure the first web space is well protected. The webril is rolled with each turn overall by 1/2–1/4 previous wrap starting from proximal to the metacarpophalangeal joints to the cubitum, followed by the casting material, and subsequent mold using 3-point molding cast technique. Example of 3-point molding technique is when if the distal fracture fragments are tipped dorsally and the apex is volar, one could hold the left-hand flat palm at the apex of the fracture, use the right hand to push the distal fracture fragments into alignment, and use a knee or another set of hands to stabilize the lateral elbow in a 3-point fixation mold.

8 Outcome Clinical Photos and Radiographs

See Figs. 5, 6, and 7.

9 Avoiding and Managing Problems

1. If reduction of the fractures to restore alignment and to correct malrotation and deviation is necessary, conscious sedation can improve cast molding after reduction.
2. Fluoroscopy (mini C-arm) improves the quality of reduction, reduces radiation exposure, and reduces the need for secondary procedures.
3. Proper molding of the cast is essential to successful management of forearm fractures.
4. Casts that are univalved or bivalved too aggressively may run a higher risk of loss of reduction.
5. The patient is observed in the ER after sedation for signs of neurovascular compromise.
6. The patient is discharged with instruction for strict elevation and warning signs of compartment syndrome.
7. Instructions before discharge on cast care include keeping the cast clean and dry and avoiding insertion of objects such as sticks or coins down inside the cast.
8. First follow-up must be done no later than 5–7 days; after that any loss of reduction and manipulation may cause additional damage to the physis and lead to premature physeal closure (growth arrest).
9. If reduction is lost after attempt of closed reduction and casting, then surgical instrumentation options should be further discussed.

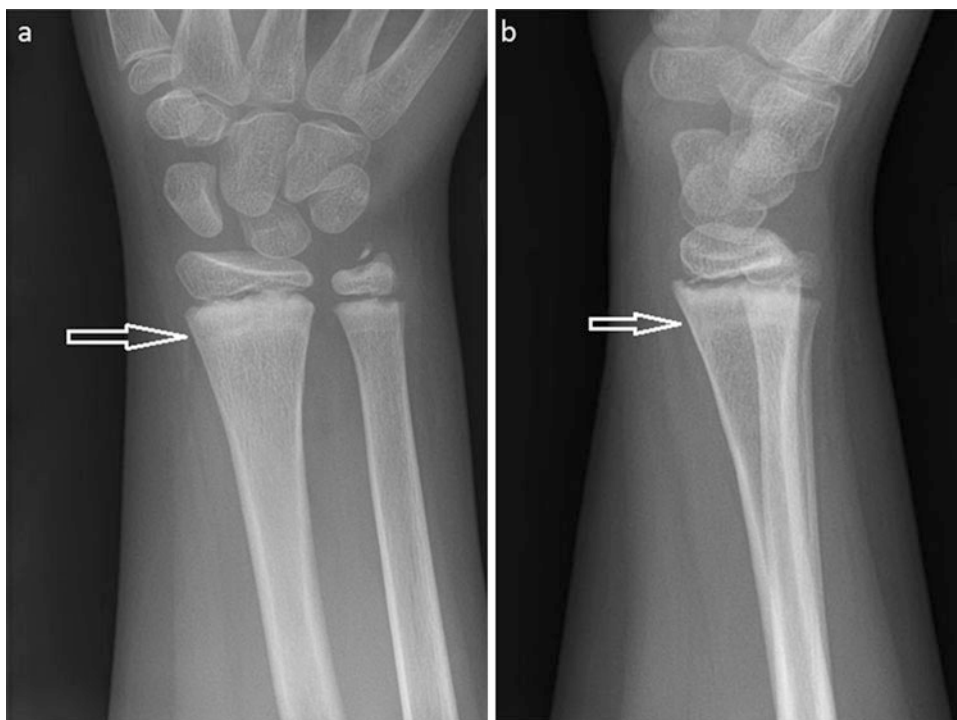
Fig. 5 Four days after reduction, (a) AP and (b) LAT radiographs show good maintenance of anatomical reduction. Twelve days after the procedure, (c) AP and (d) LAT confirm that the positioning of epiphysis has been maintained



Fig. 6 Radiographs 4 weeks (a, b) after reduction cast was removed. Radiographs 9 months after initial injury (c, d) show a well-healed fracture



Fig. 7 Park-Harris lines parallel to the distal radius (arrows) and ulna physis show no growth arrest



10 Cross-References

- [Long Arm Cast](#)
- [Munster Cast](#)

Reference and Suggested Reading

- Asadollahi S, Ooi KS, Hau RC (2015) Distal radial fractures in children: risk factors for redisplacement following closed reduction. *J Pediatr Orthop* 35(3):224–228
- Jones K, Weiner DS (1999) The management of forearm fractures in children: a plea for conservatism. *J Pediatr Orthop* 19(6):811–815
- Kamat AS, Pierse N, Devane P, Mutimer J, Horne G (2012) Redefining the cast index: the optimum technique to reduce redisplacement in pediatric distal forearm fractures. *J Pediatr Orthop* 32(8):787–791
- Vopat ML, Kane PM, Christino MA, Truntzer J, McClure P, Katarincic J, Vopat BG (2014) Treatment of diaphyseal forearm fractures in children. *Orthop Rev* 6(2):5325
- Webb GR, Galpin RD, Armstrong DG (2006) Comparison of short and long arm plaster casts for displaced fractures in the distal third of the forearm in children. *J Bone Joint Surg Am* 88(1):9–17

Part III

Spine

Pediatric Halo Application

Eric D. Shirley and Veronica Mai

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Abstract

A 4-year-old male with chondrodysplasia punctata developed progressive severe kyphoscoliosis. Growing spine instrumentation was required to prevent further progression and preserve growth potential. Preoperative halo traction was used to decrease the magnitude of the deformity before instrumentation. An eight-pin halo was applied under anesthesia using the safe zones of pin insertion. Four weeks of halo traction allowed for improvement of the deformity before growing rod instrumentation.

1 Brief Clinical History

A 4-year-old male presented with progressive kyphoscoliosis over a 2-year period. Past medical history was notable for chondrodysplasia punctata. Physical examination indicated severe short stature, severe spinal deformity, and a normal neurologic assessment.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Kyphoscoliosis
2. Chondrodysplasia punctata
3. Short stature

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4 Treatment Strategy

Treatment options included additional observation, brace treatment, combined anterior and posterior fusion, and growing rod instrumentation. Given the patient's young age with substantial growth remaining, growing instrumentation was selected. Because the small pedicle size and limited fixation points with growing instrumentation may make intraoperative correction and maintenance of fixation difficult, halo gravity traction before surgery was selected. Preoperative evaluation included a careful physical and neurologic examination. Magnetic resonance imaging was negative for intraspinal anomalies. An anesthesia consultation was obtained to identify any airway issues or other potential concerns.

5 Basic Principles

1. Halo application may be indicated to treat selected cervical spine fractures or atlantoaxial rotatory subluxation, to provide immobilization after cervical fusion, or to improve severe spinal deformity before surgery.
2. Preoperative computerized tomography (CT) scans are obtained if necessary to ensure adequate bone thickness and to avoid suture lines or congenital anomalies.
3. Halo pins are placed into the safe zones of the skull provided the skull thickness is adequate.
4. The number of pins depends on the size of the patient: 8 to 10 pins can be used in small or osteopenic patients, and

4 pins are sufficient in larger patients (as they can be tensioned to a greater magnitude).

5. Pin tensioning also depends on the size of the patient and their bone density.

6 Images During Treatment

See Figs. 2, 3, 4, 5, and 6.

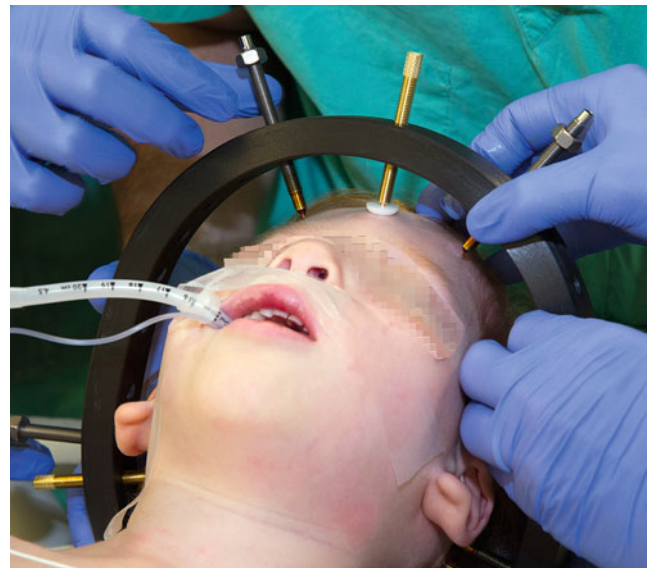


Fig. 4 Anterior pin placement respecting the safe zones of the skull



Fig. 3 A halo is selected that allows 2 cm between the skull and halo. The halo is then held in place with temporary pins



Fig. 5 Tensioning the pins

7 Technical Pearls

1. It is often easier to shave the hair above the ears before entering the operating room. The hair can be held in a rubber band during pin placement.
2. A preoperative neurologic and cranial nerve examination is documented in the medical record.
3. General anesthesia is advisable for halo application in pediatric patients. With awake patients, the eyes should



Fig. 6 Eight pins were selected because of the patient's size and the expected duration of traction

- be closed and the forehead relaxed to avoid skin tethering.
4. The surgical assistant gathers the following equipment: skin preparation solution, povidone iodine, pins, the halo, and the tensioning device.
5. A halo is selected which allows 2 cm between the skull and the halo. Temporary nonpenetrating pins hold the halo in place.
6. The skin over the anterior and posterior skull is prepped with a cleaning solution.
7. Povidone iodine is applied to the tip of the pins, which are applied perpendicular to the skull surface.
8. Optimal anterior pin placement is 1 cm superior to the orbital rim in the lateral two-thirds of the orbit (see Botte et al. 1996). This safe zone avoids the supraorbital and supratrochlear nerves and frontal sinus medially. The temporalis muscle and fossa are avoided laterally.
9. Optimal posterior pin placement is in the posterolateral skull inferior to the greatest circumference of the skull (approximately 1 cm above the top of the ear) at the 4:00 and 8:00 o'clock positions.
10. Opposite pins are tightened to the appropriate torque (2- to 5- inch pounds in patients younger than 3 years old; 6- to 8- inch pounds in older patients). Less torque (1- inch pound or finger tight) may be necessary in



Fig. 7 Photographs showing how the child tolerates the traction without substantial difficulty while in bed (a), a wheelchair (b), and a walker (c)

severely osteopenic patients. Nuts are then tightened onto the halo.

11. Neurologic examinations (including cranial nerve evaluation) are performed after halo application.
12. At 24 h after application, pins are retensioned and pin care is begun.

8 Outcome Clinical Photos and Radiographs

See Fig. 7.

9 Avoiding and Managing Problems

1. The appropriate number of pins must be selected to avoid excess torque and subsequent pin penetration.
2. A standardized physical examination protocol should be followed.
3. Pin site infection must be treated promptly.
4. Dural puncture from a fall onto the halo is a rare complication that may present with clear drainage around the pins. The tear will typically heal after the pins are changed.

10 Cross-References

- [Atlas Fractures](#)
- [Odontoid Fractures](#)
- [Pediatric Atlantoaxial Rotary Subluxation](#)

References and Suggested Reading

- Botte MJ, Byrne TP, Abrams RA, Garfin SR (1996) Halo skeletal fixation: techniques of application and prevention of complications. *J Am Acad Orthop Surg* 4(1):44–53
- Mubarak SJ, Camp JF, Vuletich W, Wenger DR, Garfin SR (1989) Halo application in the infant. *J Pediatr Orthop* 9:612–614
- Rinella A, Lenke L, Whitaker C, Kim Y, Park S, Peelle M, Edwards C, Bridwell K (2005) Perioperative Halo-Gravity traction in the treatment of severe scoliosis and kyphosis. *Spine* 30(4):475–482
- Wong WB, Haynes RJ (1994) Osteology of the pediatric skull. *Spine* 19(13):1451–1454

Atlas Fractures

Philipp Aldana and Kelly Gassie

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Abstract

Atlantoaxial posterior fixation is a well-described technique for instability in the adult population. Although also described in the pediatric population, smaller bony anatomy, synchondroses, and broad pathological conditions make this technique more challenging compared to adults. Here, we describe a young female patient who presented with a traumatic **anterior atlas fracture** after a previous suboccipital craniectomy with a C1 laminectomy. An instrumented fusion with C1 lateral mass and C2 pars

screws was chosen to stabilize her upper cervical spine. Thin cut CT scans with sagittal reconstructions and a cervical MRI were obtained to provide a thorough review of the vertebral arteries and the C2 pars and C1 lateral mass lengths and diameters. Various indications, considerations, and techniques for C1–2 fixation in the pediatric population are discussed in entry.

1 Brief Clinical History

The patient is a 17-year-old female with a symptomatic Chiari I malformation (Fig. 1), and a complex medical history including a Wilms tumor treated with a nephrectomy and chemotherapy, developmental delay, cerebral palsy, and seizures. She underwent a suboccipital craniectomy with a C1 laminectomy. Her immediate postoperative course was uneventful and she was discharged home a few days after

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the procedure. Two months after surgery, she presented to the emergency department with progressive, severe left sided neck pain after a carnival ride that caused repeated, severe, jerking movements of the head and neck.

- Paroxysmal supraventricular tachycardia
- Seizure disorder
- Wilms tumor

2 **Preoperative Clinical Photos and Radiographs**

See Figs. 1, 2, and 3.

3 **Preoperative Problem List**

- Acute anterior C1 arch fracture
- Cerebral palsy
- Chiari malformation, postdecompression
- Migraines

Fig. 1 Imaging demonstrating cerebellar tonsillar herniation inferior to C1 (*left*: Sagittal T1 without gadolinium; *right*: Sagittal T1 with gadolinium)

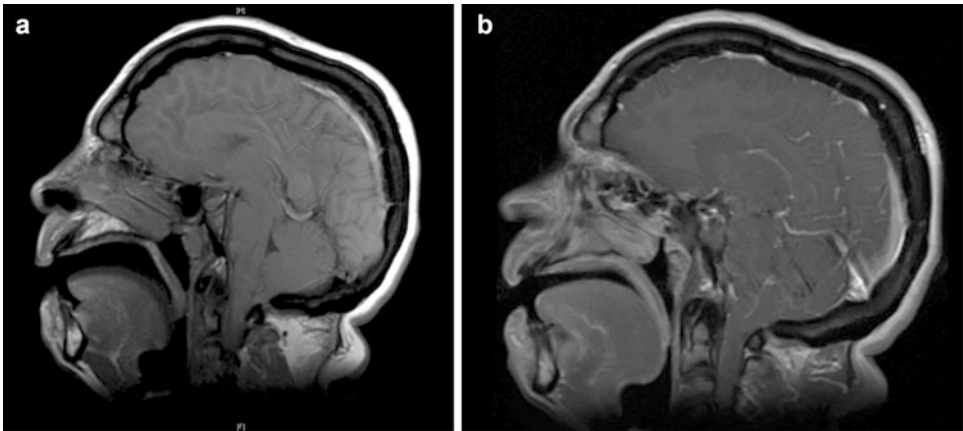
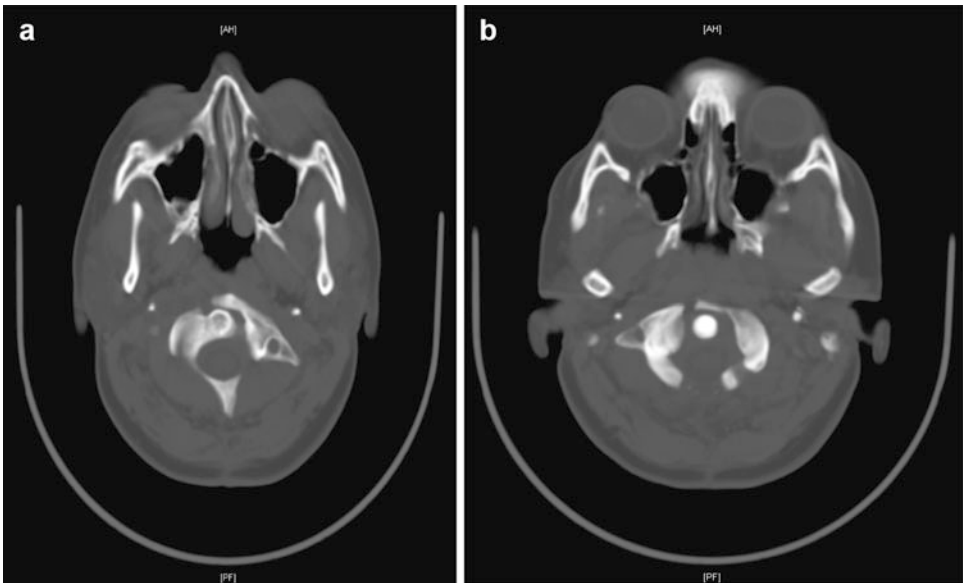


Fig. 2 CT scan revealing cortical disruption of the right parasagittal anterior arch of C1



4 **Treatment Strategy**

A CT and MRI scan of the brain and cervical spine (Figs. 2 and 3) revealed expected postoperative changes from her prior Chiari decompression, including an C1 laminectomy defect. An acute fracture of the anterior arch of C1, with a 2–3 mm gap, was noted. The patient was immobilized with a cervical collar. Rigid immobilization with a halo orthosis was considered; however, given the wide defect of her posterior cervical ring from her previous surgery, we felt it was unlikely the anterior arch fracture would heal. Therefore, a posterior instrumented fusion with C1 lateral mass–C2 pars screws was chosen.

Fig. 3 Sagittal (*left*) and axial (*right*) T2 MRI images of the C-Spine showing a minimally distracted fracture at the right parasagittal anterior arch without evidence of transverse ligament disruption or abnormal soft tissue swelling



5 Basic Principles

Traditional surgical treatment for a *Chiari I malformation* consists of a suboccipital craniectomy with a C1 laminectomy. The amount of laminectomy is dictated by the level of tonsillar herniation. Some may extend the decompression to include C2 and C3 depending on the level of tonsillar decent. Little is known regarding post laminectomy cervical instability in these patients or the best techniques to stabilize them.

Pediatric spine fractures most commonly involve the upper cervical spine. Atlas fractures typically occur during excessive axial loading (Anderson et al. 2007). It is likely that defects of the posterior arch compromise the resistance of the atlas to deformation and make C1 more susceptible to anterior arch fractures. Anterior atlas fractures in pediatrics patient are often associated with congenital defects of the anterior or posterior arch. Anterior atlas fractures after suboccipital decompressions with C1 laminectomies for Chiari I malformations are rare (Haque et al. 2009).

Oshaughnessy et al. reported a case of an anterior atlas fracture after a C1 laminectomy. The patient presented 5 months postoperatively after a violent coughing episode (Haque et al. 2009). The patient was initially treated conservatively with a hard collar, but subsequently developed instability and displacement of the anterior arch fracture, and then underwent a posterior spinal fusion.

There are various surgical techniques for **C1–2 fixation** in pediatric patients. Options include C1–C2 transarticular screws, C1 lateral mass, C2 lateral mass, pars, or laminar screws, or wiring techniques. Extensive preoperative imaging is key before any of these techniques to avoid potentially catastrophic vascular injuries and to obtain information about the suitability of the patient's C1–C2 anatomy for safe drilling and screw placement.

Rigid internal fixation at the atlantoaxial level in children has historically been controversial due to variable anatomy, smaller bone size, and unfamiliarity with instrumentation of the pediatric cervical spine. However, the use of thin cut CT scans and the development of stereotactic methods for safe screw trajectories now allow safe, posterior instrumented fixation for pediatric patients.

For all of the following techniques, patients are positioned prone with the cranium rigidly attached to the operating room table.

5.1 C1–C2 Transarticular Screw Fixation Technique

C1–C2 transarticular screws are an appropriate choice when anatomically possible. The fixation involves four cortical surfaces and can be anatomically and technically demanding (Dickman et al. 1991). The importance of extensive preoperative imaging cannot be stressed enough. Imaging findings that make this technique unsuitable for fixation include the location of the vertebral artery precluding safe screw placement (e.g., C2 transverse foramen narrowing the C2 pars), or inadequate bone thickness for a 3.5 mm screw. The entry point on C2 is 2–3 mm superior to the inferior edge of the C2 inferior articular process and 2–3 mm lateral to the junction of the lamina and the lateral mass. The screw path is directed 2–5° medially in the parasagittal plane and inferiorly toward the superior half of the anterior C1 lamina on lateral fluoroscopic imaging. This trajectory incorporates the C2 pars interarticularis along the central axis of the C2 isthmus. The final screw trajectory should incorporate the C2 pedicle, C2 pars, C1–2 joint space, and lateral mass of C1 (Brockmeyer et al. 2000).

5.2 C1 Lateral Mass-C2 Pars Screws

The cervical spine is first exposed from the occiput to C3–4. (Harms and Melcher 2001) There is a robust venous plexus between C1 and C2, which can be controlled with bipolar coagulation and hemostatic agents. Dissection over the superior surface of the C2 pars exposes a key anatomic landmark for C1 lateral mass screw placement. Commonly, the C2 nerve root is displaced caudally to expose the lateral mass of C1. At this point, the surgeon can palpate the junction of the C1 lamina to the lateral mass and a pilot hole is placed in the center of the lateral mass. The drill is directed 10° medial in the axial plane, towards the anterior tubercle of C1. Drilling should terminate just short of the anterior tubercle of C1 to prevent violation of the retropharyngeal space.

The C2 screw is placed into the pars. The entry point for the screw is around 3 mm rostral and 3 mm lateral to the inferior articulating facet. The screw trajectory is 45–60° cephalad and 10–15° medial, stopping short of the transverse foramen. A dissector on the medial border of the pars can be used to mark the medial boundary of the screw trajectory.

5.3 C2 Laminar Screws

The translaminar screw fixation technique of the axis, described by Wright (Wright 2005), is less technically demanding compared to other methods, with less risk to the vertebral artery. It does not require intraoperative imaging to guide placement, due to direct visualization of the lamina. At the junction of the spinous process and lamina of C2, a high-speed drill can be used to penetrate the cortical bone. Maintaining a trajectory less than the downslope of the lamina, a screw can be inserted within the laminar trabecular bone. The laminar polyaxial screw heads will face the spinous process of

C2 in their final position. In children, the diameter of the lamina can limit the placement of the screws in either lamina.

5.4 C1–2 Bony Fusion

Placement of an interspinous structural bone graft, held rigidly in place by a sublaminar cable, can be used to augment C1–2 instrumentation and to serve as a substrate for bony fusion. Although less rigid than screws and rods, the C1–2 cable fusion technique can provide adequate fixation if other techniques are not possible (Dickman et al. 1991). A single bicortical graft is used with a titanium cable passing sublaminar to C1 and around the spinous process of C2. The bone graft is wedged between C1 and C2 for an interspinous fusion. The graft is most commonly taken from the posterior iliac crest, but allografts have also been described. If the posterior ring of C1 or C2 is not intact, as in this patient, this technique is not appropriate. As an alternative, morcellized bone graft may be inserted in the C1–2 joint following exposure, curettage, and decortication. If remnants of the C1 lamina remain laterally, only morcellized bone graft or structural graft can be used to bridge the C2 lamina and remaining C1 lamina.

6 Images During Treatment

See Fig. 4.

7 Technical Pearls

- Obtain adequate imaging studies, including axial thin cut CTs of the cervical spine with sagittal reconstructions, and an MRI of the cervical spine.

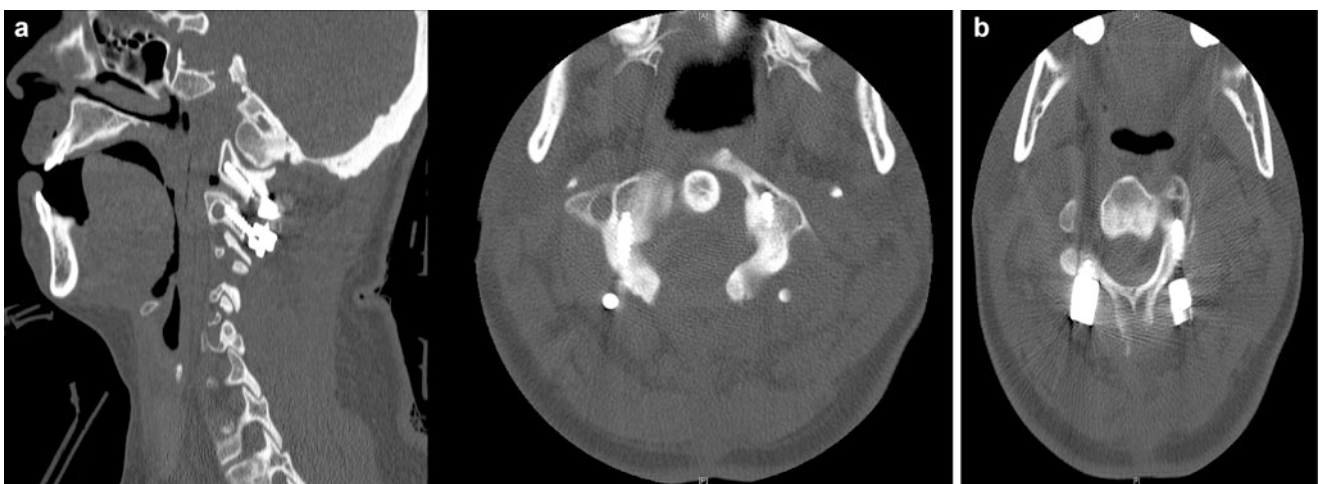
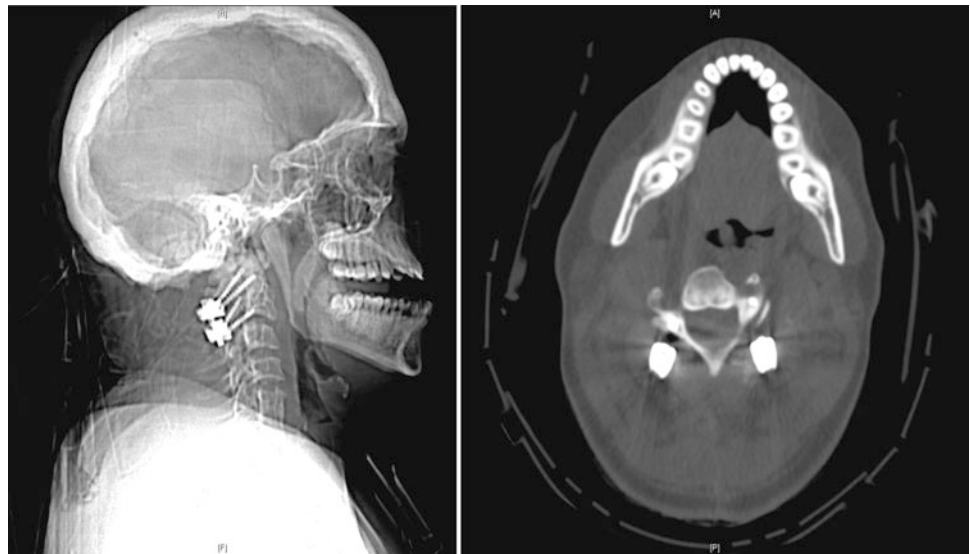


Fig. 4 (a–b) Axial and sagittal CT scans showing the C1 lateral mass (a) and C2 pars screws (b)

Fig. 5 (Left) Final sagittal film showing C1 lateral mass and C2 pars screws. (Right) Axial section of C2 pars screws. Cancellous allograft bone chips were placed between the C1–2 laminae bilaterally



- Using the imaging studies:
 - Identify the course of the vertebral arteries in relation to C1 and C2.
 - Identify the C2 pars lengths and diameters. Estimate the course of the screws within the C2 pars. Measure the distance of the screw path in C1 and C2 to determine a safe depth for drilling and safe screw length.
 - Examine the C1 lateral mass to visualize the course of the screw in the lateral mass.
- The neck should be in the neutral position.
- The surgical exposure should extend from the foramen magnum to C3–4.
- Lateral fluoroscopic images are necessary to help guide C1 lateral mass screw placement. Stereotactic image guidance can be helpful in situations with difficult anatomy.
- The venous plexus surrounding the C2 nerve roots may be quite robust. Bipolar coagulation can be used to shrink these prior to exposure of the C1 lateral mass screw entry sites.
- After placement of instrumentation, tailor bone graft to maximize the contact of cortical bone between the graft and the posterior elements of C1 and C2.
- Understand alternative techniques of fixation for C1–2, the occiput, and the subaxial spine
- Be vigilant to maintain a proper trajectory while preparing screw paths and do not exceed the predetermined safe depth for drilling and the length of the screws.
- In the event of a suspected vertebral artery injury during placement of a C2 pars screw, continue placement of the screw (provided there is good fixation). If the contralateral screw has not been placed, forego placement of this screw to prevent bilateral vertebral artery injury. Augment fixation with C1–2 cables. Obtain a cerebral angiogram to evaluate for vertebral artery injury and the status of the collateral circulation.
- In younger children with more delicate cervical vertebrae, a halo crown and vest may be used if bony purchase or fixation is inadequate.

8 Outcome Clinical Photos and Radiographs

See Fig. 5.

9 Avoiding and Managing Problems

- Be prepared to extend the fusion rostrally and caudally if C1–2 fixation is inadequate or impossible.

10 Cross-References

- [Pediatric Halo Application](#)
- [Pediatric Traumatic Spondylolisthesis of the Axis](#)

References and Suggested Reading

- Anderson RC, Ragel BT, Mocco J et al (2007) Selection of a rigid internal fixation construct for stabilization at the craniovertebral junction in pediatric patients. *J Neurosurg* 107 (1 Suppl):36–42
- AuYong N, Piatt J Jr (2009) Jefferson fractures of the immature spine. Report of 3 cases. *J Neurosurg Pediatr* 3(1):15–19
- Baghdassarian A, Piatt JH, Giordano K (2014) Fracture of the anterior arch of atlas after minor trauma of the immature spine post-laminectomy. *Pediatr Emerg Care* 30(5):340–342

- Brockmeyer DL, York JE, Apfelbaum RI (2000) Anatomical suitability of C1-2 transarticular screw placement in pediatric patients. *J Neurosurg* 92(1 Suppl):7–11
- Crostelli M, Mariani M, Mazzo O et al (2009) Cervical fixation in the pediatric patient: our experience. *Eur Spine J* 18(Suppl 1): 20–28
- Dickman CA, Sonntag VK, Papdopoulos SM et al (1991) The interspinous method of posterior atlantoaxial arthrodesis. *J Neurosurg* 74(2):190–198
- Haque A, Price AV, Skylar FH et al (2009) Screw fixation of the upper cervical spine in the pediatric population. Clinical article. *J Neurosurg Pediatr* 3(6):529–533
- Harms J, Melcher RP (2001) Posterior C1-C2 fusion with polyaxial screw and rod fixation. *Spine (Phila Pa 1976)* 26 (22):2467–2471
- Heuer GG, Hardesty DA, Bhowmick DA et al (2009) Treatment of pediatric atlantoaxial instability with traditional and modified Goel-Harms fusion constructs. *Eur Spine J* 18(6):884–892
- Jeanneret B, Magerl F (1992) Primary posterior fusion C1/2 in odontoid fractures: indications, technique, and results of transarticular screw fixation. *J Spinal Disord* 5(4):464–475
- Kakarla UK, Chang SW, Theodore N et al (2010) Atlas fractures. *Neurosurgery* 66(3 Suppl):60–67
- O'Shaughnessy BA, Salehi SA, Ali S et al (2004) Anterior atlas fracture following suboccipital decompression for Chiari I malformation. Report of two cases. *J Neurosurg Spine* 1(1):137–140
- Rahimi SY, Stevens A, Yeh DJ et al (2003) Treatment of atlantoaxial instability in pediatric patients. *Neurosurg Focus* 15(6):ECP1
- Wright NM (2005) Translaminar rigid screw fixation of the axis. Technical note. *J Neurosurg Spine* 3(5):409–414

Pediatric Atlantoaxial Rotary Subluxation

Kevin M. Neal

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Abstract

Atlantoaxial rotary subluxation (AARS) is a relatively rare condition in children, characterized by the acute onset of fixed torticollis. The cause often remains elusive, but all cases are generally felt to be due to some form of inflammation, which can occur secondary to infection, an autoimmune process, or trauma. Trauma causing AARS can vary from significant injuries such as falls or motor vehicle accidents to more minor injuries such as a bump to the head or neck manipulation during surgery. Treatments are focused on reducing the subluxated atlantoaxial joints, and methods range from cervical collars, to cervical traction, to open reduction of the joints. This chapter presents a case of pediatric AARS and the author's preferred algorithm for treatment.

A 7-year-old boy presented 1 week after developing the acute onset of torticollis. Attempts to straighten his neck were painful. He denied any history of recent infection, upper respiratory illness, antibiotic use, or recent surgery. His neurologic exam was normal. Radiographs of the cervical spine taken in the clinic were unremarkable. A diagnosis of acute AARS was made, and the patient was initially treated with a cervical collar and anti-inflammatory medication. The torticollis did not resolve, and 2 weeks later an MRI of the cervical spine was obtained. The MRI confirmed subluxation of the atlantoaxial joints and ruled out an infectious process. The patient was placed into cervical halter traction in the hospital and given benzodiazepines for muscle relaxation. After 2 weeks of halter traction, the torticollis failed to reduce. A cranial halo was placed under anesthesia, and skeletal traction was applied. After 1 week of skeletal traction, the torticollis resolved. The halo was incorporated into halo-vest immobilization of the cervical spine, which was continued for 3 months. After 3 months, the halo was removed, and the patient regained full, normal range of motion of the cervical spine.

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1 Brief Clinical History

A 7-year-old boy bumped his head while playing with his brother. When he awoke the next morning, he held his head in a “cock-robin” position (Fig. 1), and attempts to straighten his neck were painful. When the torticollis did not resolve after a week, his parents brought him to the doctor for evaluation. He denied any history of recent infection, upper respiratory illness, antibiotic use, or recent surgery. His neurologic exam was normal. Radiographs of the cervical spine taken in the clinic were unremarkable.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Acute atlantoaxial rotary subluxation

4 Treatment Strategy

AARS is typically a clinical diagnosis. Because the atlantoaxial joints naturally sublux with normal neck rotation, patients with clinical fixed torticollis have subluxation of these joints by definition. If there is suspicion for an infectious cause of inflammation causing AARS, laboratory studies, including a CBC, ESR, and CRP, can be obtained. Radiographs are most commonly normal but can be used as a baseline to rule out more significant injury such as a cervical spine fracture. Advanced imaging with CT scans has been advocated in the past, but may not help advance the treatment algorithm, and may impart an unacceptable amount of radiation to the neck of a growing child. MRI scans can be used if there is suspicion of an infectious process that can be treated such as a retropharyngeal abscess.

Treatment options are typically based on the amount of time from the onset of symptoms, and include using a cervical collar and anti-inflammatory medication to try to relax the cervical muscles and allow a spontaneous reduction of the atlantoaxial joints, using halter or skeletal traction with benzodiazepines to reduce the joints, or open reduction with internal fixation. For cases that present less than 2 weeks from the onset of symptoms, trying a cervical collar and NSAIDs is appropriate, and successful in the majority of cases.

If symptoms persist despite use of the collar, patients can be admitted to the hospital for supervised cervical halter traction and benzodiazepines for muscle relaxation. Patients



Fig. 1 Clinical photograph of the patient showing the acute “cock-robin” torticollis positioning of the neck (Adapted with permission from Wolters Kluwer: Spine, Ken Ishii, Morio Matsumoto, Suketaka Momoshima, et al., Remodeling of C2 Facet Deformity Prevents Recurrent Subluxation in Patients With Chronic Atlantoaxial Rotatory Fixation: A Novel Strategy for Treatment of Chronic Atlantoaxial Rotatory Fixation, 2011)

can be started with small amounts of weight, and the weight can be increased 2–3 pounds per day, up to about 50% of body weight. Frequent neurologic checks, including cranial nerve exams, are required for patients in cervical traction. If the halter traction is successful, patients are maintained in a cervical collar for 3 months to prevent recurrence.

If halter traction fails to reduce AARS, skeletal traction can be applied. The author’s preferred method is to place a cranial halo under anesthesia. For children, 6–8 pins should be used due to the thinner bone of immature skulls. Care should be taken to avoid the temporalis muscles and the supraorbital nerves when placing pins. Weight can be gradually increased, while performing serial neurologic examinations, in the same manner as that used for halter traction (Fig. 2). If skeletal traction is successful, patients are maintained in halo vests for 3 months to prevent recurrence.

If halter traction and skeletal traction both fail to reduce the AARS, open reduction and C1-2 arthrodesis are typically required.

5 Basic Principles

Halo Traction:

1. In children, cranial halos are typically placed under a general anesthesia.

Fig. 2 (a) A clinical photograph of a child with a cranial halo in place. Two pins are placed on either side anteriorly above the lateral portion of each eyebrow. Two pins are placed on either side posteriorly just above and behind the pinna of the ear. (b) Clinical photograph of a child lying in bed in halo-gravity traction

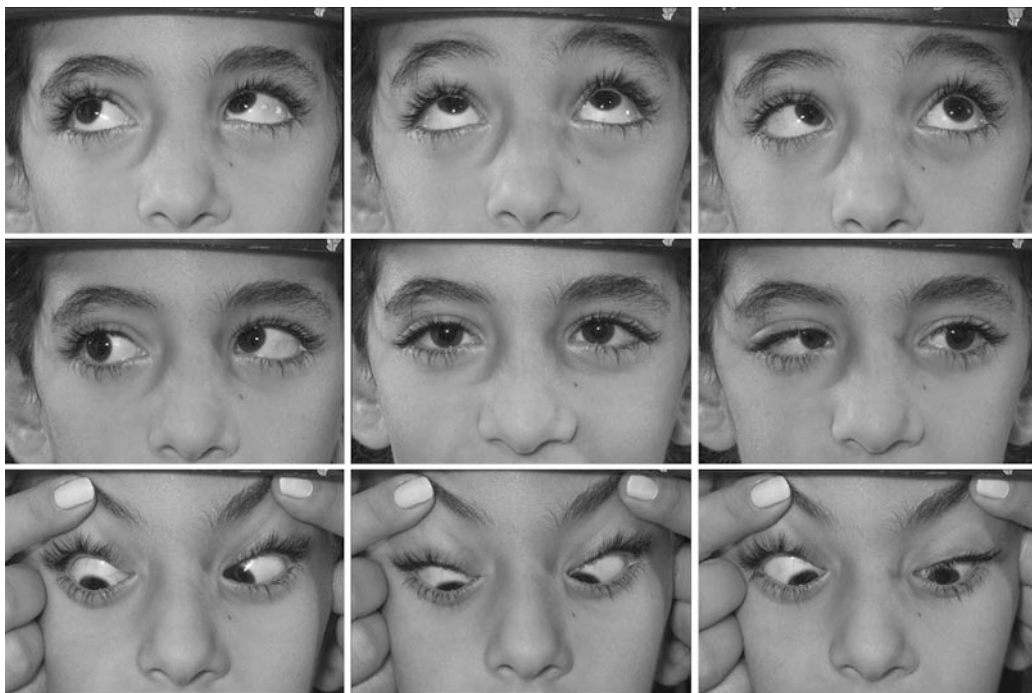
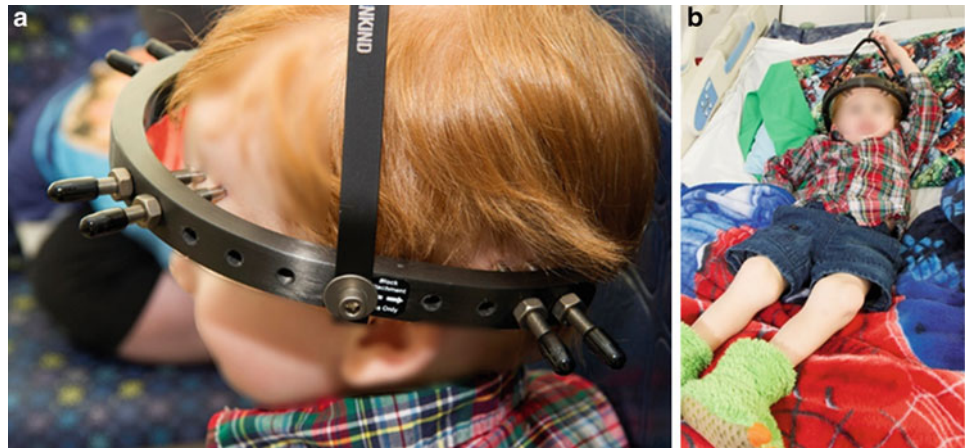


Fig. 3 (a) Abnormal lateral gaze of the right eye while the patient is attempting to look toward the right side, indicative of an abducens cranial nerve palsy. (b) Abnormal tongue thrust while the patient is attempting to stick the tongue straight out, indicative of a hypoglossal cranial nerve palsy (Reprinted from Journal of American Association for

Pediatric Ophthalmology and Strabismus, 8, Emma Pinches, Dominic Thompson, Hilali Noordeen, Alki Liasis, Ken K. Nischal, Fourth and sixth cranial nerve injury after halo traction in children: A report of two cases, 580–585, Copyright (2004), with permission from Elsevier)

- In children, 6–8 pins are used, and each is tightened to between 2 and 5 inch-pounds of torque, due to the thinner nature of the immature skull.
- The pin sites are prepped with chlorhexidine.
- Anteriorly, two pins are placed on either side, 1 cm above the lateral portion of each eyebrow.
- Posteriorly, one or two pins are placed 1 cm above, and just posterior to the pinna of each ear.
- The pin sites can be cleaned daily with soap and water.
- Weight is typically initiated with 5 pounds and can be increased 2–3 pounds every day, up to about 50% of body weight (Fig. 2).
- Frequent neurologic examinations are required, including shortly after each addition of weight, including checking the cranial nerves.
- Typically, up to 2 weeks is allowed for reduction of AARS using skeletal traction, before proceeding with open reduction and fusion of C1-2.

10. Once reduction of the AARS has been achieved, the halo traction can be converted to halo-vest immobilization to maintain the reduction for 3 months.

6 Images During Treatment

See Figs. 2 and 3.

7 Technical Pearls

1. The halo should be placed just inferior to the equator of the skull (the area of the greatest skull diameter).
2. Hair is removed behind the ears to avoid getting tangled in the pins.
3. The pressure on each pin is rechecked 1 day after halo placement using a torque wrench, to ensure no loosening.
4. Traction is meant to be continuous, but weight can be safely removed, if needed, for bathing, trips to the restroom, or general comfort and sleep.
5. The most common cranial nerve palsies are to the abducens nerve, which causes loss of lateral gaze, and to the hypoglossal nerve, which causes asymmetry of the tongue. (Fig. 3).
6. The weights can be removed and replaced daily to allow for examination of the torticollis to determine its persistence or resolution.

8 Avoiding and Managing Problems

1. Use proper anterior pin placement to avoid the temporalis muscle and the supraorbital nerves.
2. Include examinations of the cranial nerves, especially the abducens and hypoglossal nerves, for patients in cervical traction.

9 Cross-References

- [Atlas Fractures](#)
- [Odontoid Fractures](#)
- [Pediatric Halo Application](#)
- [Unilateral Cervical Facet Fracture-Dislocation](#)

References and Suggested Readings

- Alanay A, Hicazi A, Acaroglu E et al (2002) Reliability and necessity of dynamic computerized tomography in diagnosis of atlantoaxial rotatory subluxation. *J Pediatr Orthop* 22(6):763–765
- Beier AD, Vachhrajani S, Bayerl SH, Aguilar CY, Lamberti-Pasculli M, Drake JM (2012) Rotatory subluxation: experience from the hospital for sick children. *J Neurosurg Pediatr* 9(2): 144–148
- Chechik O, Wientroub S, Danino B, Lebel DE, Ovadia D (2013) Successful conservative treatment for neglected rotatory atlantoaxial dislocation. *J Pediatr Orthop* 33(4):389–392
- Ishii K, Toyama Y, Nakamura M, Chiba K, Matsumoto M (2012) Management of chronic atlantoaxial rotatory fixation. *Spine (Phila Pa 1976)* 37(5):E278–E285
- Landi A, Pietrantonio A, Marotta N, Mancarella C, Delfini R (2012) Atlantoaxial rotatory dislocation (AARD) in pediatric age: MRI study on conservative treatment with Philadelphia collar – experience of nine consecutive cases. *Eur Spine J* 21(Suppl 1): S94–S99
- Lavelle WF, Palomino K, Badve SA, Albanese SA (2017) Chronic C1–C2 rotatory subluxation reduced by C1 lateral mass screws and C2 translaminar screws: a case report. *J Pediatr Orthop* 37(3): e174–e177
- Mifsud M, Abela M, Wilson NI (2016) The delayed presentation of atlantoaxial rotatory fixation in children: a review of the management. *Bone Joint J* 98-B(5):715–720
- Mubarak SJ, Camp JF, Vuletich W, Wenger DR, Garfin SR (1989) Halo application in the infant. *J Pediatr Orthop* 9(5):612–614
- Neal KM, Mohamed AS (2015 Jun) Atlantoaxial rotatory subluxation in children. *J Am Acad Orthop Surg* 23(6):382–392
- Pang D (2010) Atlantoaxial rotatory fixation. *Neurosurgery* 63(Suppl 3):161–183
- Tauchi R, Imagama S, Ito Z et al (2013) Surgical treatment for chronic atlantoaxial rotator fixation in children. *J Pediatr Orthop B* 22(5):404–408

Odontoid Fractures

John F. Lovejoy, Jeffrey E. Martus, and Megan M. Mizera

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Abstract

Pediatric odontoid fractures are rare but should be suspected in any child at risk for cervical spine trauma. Injuries to the odontoid have occurred even with relatively minor injuries such as ground-level falls. The fulcrum of motion in pediatric patients is at the C2-C3 level resulting in a greater risk of upper cervical fractures. Under the age of 7 years, the most common odontoid fracture is through the cartilaginous synchondrosis between the odontoid process and the body of the axis. Adolescents who sustain an odontoid fracture after synchondrosis fusion can be classified using the Anderson and D'Alonzo criteria and treated appropriately. A thorough clinical and radiographic evaluation is critical. Treatment options include both non-operative and operative options. Synchondrosis fractures will heal reliably with external immobilization. Non-union after treatment is rare. Surgery is reserved for patients

who fail conservative treatment, with loss of reduction, nonunion, or neurological symptoms. A neurological deficit is uncommon with these injuries. If an odontoid fracture is neglected, nonunion may occur with the development of an os odontoideum and subsequent atlantoaxial instability. This chapter discusses non-operative and operative treatment, imaging studies, and potential complications in the management of pediatric odontoid fractures.

1 Brief Clinical History

A 3-year-old male was involved in a rollover motor vehicle accident where the family minivan struck a tree. He was appropriately restrained in a car seat and airbags were noted to have deployed. At the scene, he was awake, alert, and moving all extremities spontaneously. He was immobilized in a cervical collar and transported to a local hospital (Fig. 1). A CT scan was obtained demonstrating a displaced odontoid fracture (Fig. 2). Spinal precautions were continued, and he was transferred by ambulance to a pediatric trauma center for definitive care.

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Fig. 1 Initial immobilization should consist of an appropriately sized pediatric cervical collar. Due to the disproportionate large head of children less than age 8 years, a backboard with an occipital recess should be used to avoid excessive cervical flexion



Fig. 2 Sagittal reconstruction of a CT scan demonstrating an odontoid fracture with displacement through the dentocentral synchondrosis

2 Preoperative Radiographs

Odontoid synchondrosis fractures are most commonly displaced anteriorly with some degree of angulation. A lateral radiograph may be adequate to make the diagnosis; however, this fracture can be missed on plain radiographs. The addition

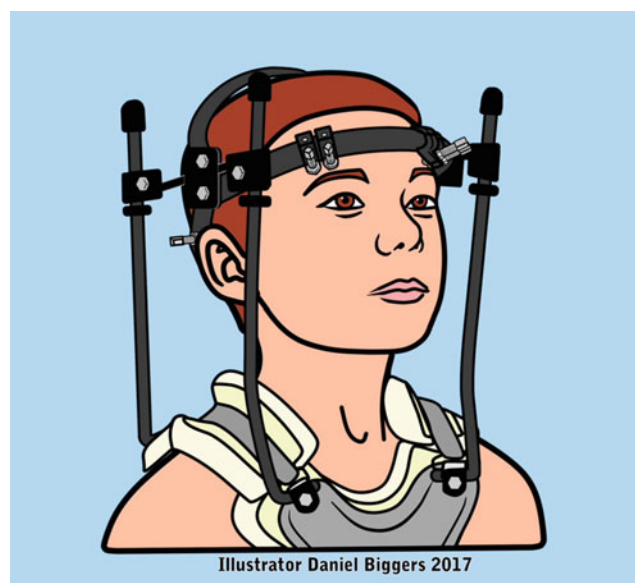


Fig. 3 Illustration of a pediatric halo with two pins placed on each side anterolaterally

of cross sectional imaging, either CT or MRI, should be considered for any child who is unresponsive, intubated, has positive neurological findings on clinical exam, or in whom a high clinical suspicion of a cervical injury exists despite the presence of normal radiographs. A CT scan with coronal and sagittal reformats is effective at identifying odontoid fractures and other cervical injuries. Alternatively, an MRI is capable of both identifying fractures as well as define the extent of soft tissues injuries and avoids exposing the patient to additional radiation.

3 Preoperative Problem List

- Displaced odontoid fracture without neurologic deficit

4 Treatment Strategy

The primary treatment of pediatric odontoid fractures is non-operative. Immobilization with a halo vest (Fig. 3) or Minerva cast for 6–12 weeks can be used (Figs. 4 and 5). Synchondrosis fractures will heal reliably with external immobilization. Nonunion of an adequately treated odontoid fracture is rare in a young child. Surgery is reserved for patients who fail conservative treatment, with loss of reduction, nonunion, or neurological symptoms. Surgical treatment introduces a risk of complications due in part to the patient's smaller physical size and remaining growth potential. When required, C1-C2 arthrodesis is performed with internal fixation, consisting of posterior wiring with structural bone graft,



Fig. 4 Coronal view of a 13-month-old in a Minerva cast

atlantoaxial transarticular screws, or C1 lateral mass screws combined with C2 pars screws. Of note, the long-term effects of upper cervical fusion in a young child remain unknown.

5 Technical Pearls

An unstable C2 synchondrosis fracture is reduced under fluoroscopy with gentle cervical extension (Fig. 6). Once a successful reduction is obtained, immobilization is required. A Minerva cast is very effective, particularly for infants; however it does require skillful application. Adequate padding and avoidance of pressure on bony prominences and the ears are critical to avoid skin breakdown.

Alternatively, a halo vest is an excellent treatment option, providing excellent stability while also allowing caretakers greater access to the child. When applying a halo, it is important to remember the anterior safe zone for pin insertion, which is just superior to the lateral 2/3 of the eyebrow (Fig. 7). During insertion of the anterior pins, the eyes should be closed, and gentle caudal skin traction should be placed on the eyebrow to avoid tethering the skin cranially. Posterior pins should be placed opposite to the anterior pins, taking care to leave clearance between the halo ring and the ears.



Fig. 5 Sagittal view of a 13-month-old in a Minerva cast

For children older than age 6 years, a standard four-pin configuration (two anterolaterally and two posterolaterally) may be utilized, torquing the pins at 6 to 8 in.-lbs. For younger children, the pin insertion technique must be modified to limit the risk of skull perforation. In this age group, a greater number of pins (up to four anterolaterally and up to six posterolaterally) may be placed with lower insertional torques. A general guideline is finger tight pins for infants and a torque of 1 in.-lb per year of life under the age of 6 years.

An upright radiograph in the cast or halo vest is important to confirm adequate alignment after the reduction (Fig. 8). The fracture is then followed with serial radiographs. Once adequate healing is judged by radiographs and/or CT scans, the cast or halo immobilization is discontinued, and the patient is transitioned into a cervical collar. The patient gradually weans from the use of the collar over the upcoming weeks. One month later, lateral cervical flexion-extension films are obtained to confirm that there is no motion at the fracture site or other instability (Figs. 9, 10, and 11).

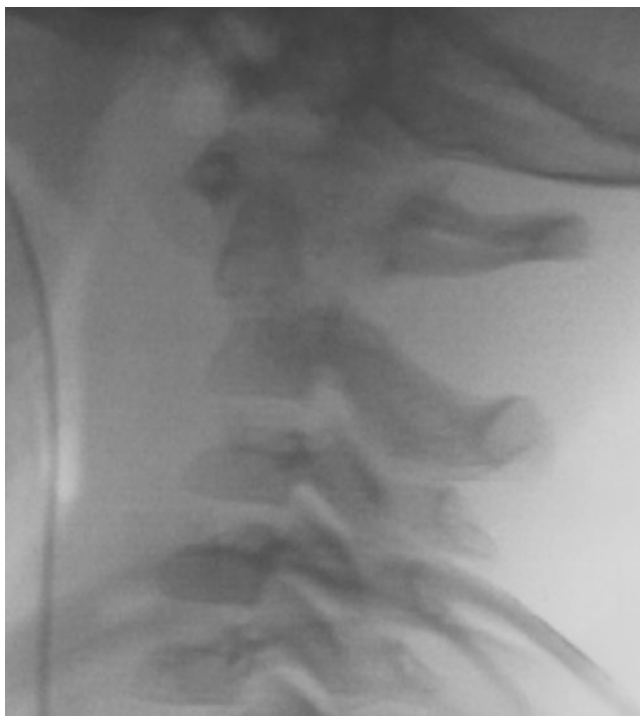


Fig. 6 An eight-pin halo ring was applied under general anesthesia with the pins torqued to 3 in.-lbs. The odontoid fracture was reduced with fluoroscopic control, and a halo vest was applied



Fig. 8 An upright radiograph in the halo vest demonstrates adequate alignment of the odontoid fracture

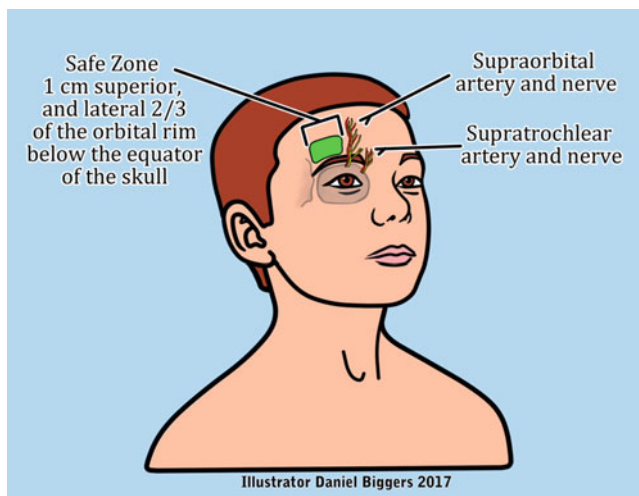


Fig. 7 The anterior safe zone for pin insertion is just superior to the lateral 2/3 of the eyebrow

Nonunion is rarely encountered in the management of pediatric odontoid fractures. However, in older adolescents, nonunion may occur despite adequate immobilization in a halo vest.



Fig. 9 Lateral radiograph demonstrating the healed odontoid fracture 6 weeks following the injury



Fig. 10 Lateral flexion radiograph demonstrating no evidence of instability 10 weeks following the injury



Fig. 11 Lateral extension radiograph demonstrating no evidence of instability 10 weeks following the injury

6 Avoiding and Managing Problems

Problems in the management of pediatric odontoid fractures are specific to the treatment technique:

6.1 Non-operative Treatment (Minerva Cast or Halo Vest Immobilization)

The preoperative imaging (CT head) should be scrutinized for a skull fracture or anatomic variants which could be problematic with halo pin placement. During application of the halo, pin placement into the medial 1/3 of the orbit is to be avoided due to the presence of the supraorbital and supra-trochlear nerves and artery.

Observe carefully for evidence of skin breakdown during the treatment period. While the child is in a halo vest, activity restriction is critical as a fall in the halo may lead to a skull fracture or other complication. Pin tract infections are common and may be minimized with daily pin care. If a superficial infection is noted, a short course of oral antibiotics is usually adequate to clear the infection.

6.2 Operative Treatment (C1-C2 Arthrodesis)

Potential surgical complications include but are not limited to superficial or deep infection, vertebral or internal carotid artery injury, nerve root or spinal cord injury, nonunion, implant malposition, and hardware failure.

References and Suggested Readings

- Anderson LD, D'Alonzo RT (1974) Fractures of the odontoid process of the axis. *J Bone Joint Surg Am* 56:1663–1674
- Blauth M et al (1996) Fractures of the odontoid process in small children: biomechanical analysis and report of three cases. *Eur Spine J* 5:63–70
- Fassett DR et al (2008) Odontoid fractures in pediatric and adult patients: atlas of spine and trauma. Elsevier, Philadelphia, pp 196–209
- Gluf WM, Brockmeyer DL (2005) Atlantoaxial transarticular screw fixation: a review of surgical indications, fusion rate, complications, and lessons learned in 67 pediatric patients. *J Neurosurg Spine* 2:164–169
- Mandabam M, Ruge RJ, Hahn YS, McLone DG (1993) Pediatric axis fractures: early halo immobilization, management and outcome. *Pediatr Neurosurg* 19:225–232

- Martus JE, Mencia GA (2014) Fractures of the spine. In: Skeletal trauma in children, 5th edn. Elsevier
- Odent T et al (1999) Fractures of the odontoid process: a report of 15 cases in children younger than 6 years. *J Pediatr Orthop* 19(1):51–54
- Sherk HH (1998) Developmental anatomy of the normal cervical spine. In: Clark CR (ed) *The cervical spine*, 3rd edn. Lippincott-Raven Publishers, Philadelphia, pp 37–44
- Sherk HH et al (1978) Fractures of the odontoid process in young children. *J Bone Joint Surg Am* 60:921–924

Pediatric Traumatic Spondylolisthesis of the Axis

Alexandra D. Beier

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Abstract

An 18-month-old male suffered spondylolisthesis of the axis after a motor vehicle accident. The injury was initially not diagnosed. Three months later, he presented with C2–C3 subluxation and kyphosis that required operative intervention. This chapter will address nuances associated with the management of pediatric patients with C2 pedicle fractures.

1 Brief Clinical History

An 18-month-old male was involved in a severe motor vehicle accident. An outside hospital without pediatric specialists obtained a computed tomography (CT) scan of the cervical spine which was interpreted as normal (Fig. 1a–d), cleared

his C-spine and discharged him without a cervical collar. He had limitation of his range of motion, specifically flexion and extension, and was referred to physical therapy. Due to lack of progress and persistent limitation of flexion-extension, he was referred back to the outside hospital for evaluation 3 months after his injury. A lateral X-ray was performed that revealed C2–C3 subluxation with kyphosis and angulation (Fig. 2). He was placed in a cervical collar and transferred to our institution for further evaluation. Upon our evaluation, he was noted to be neurologically intact, except for hyperreflexia in his lower extremities.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4.

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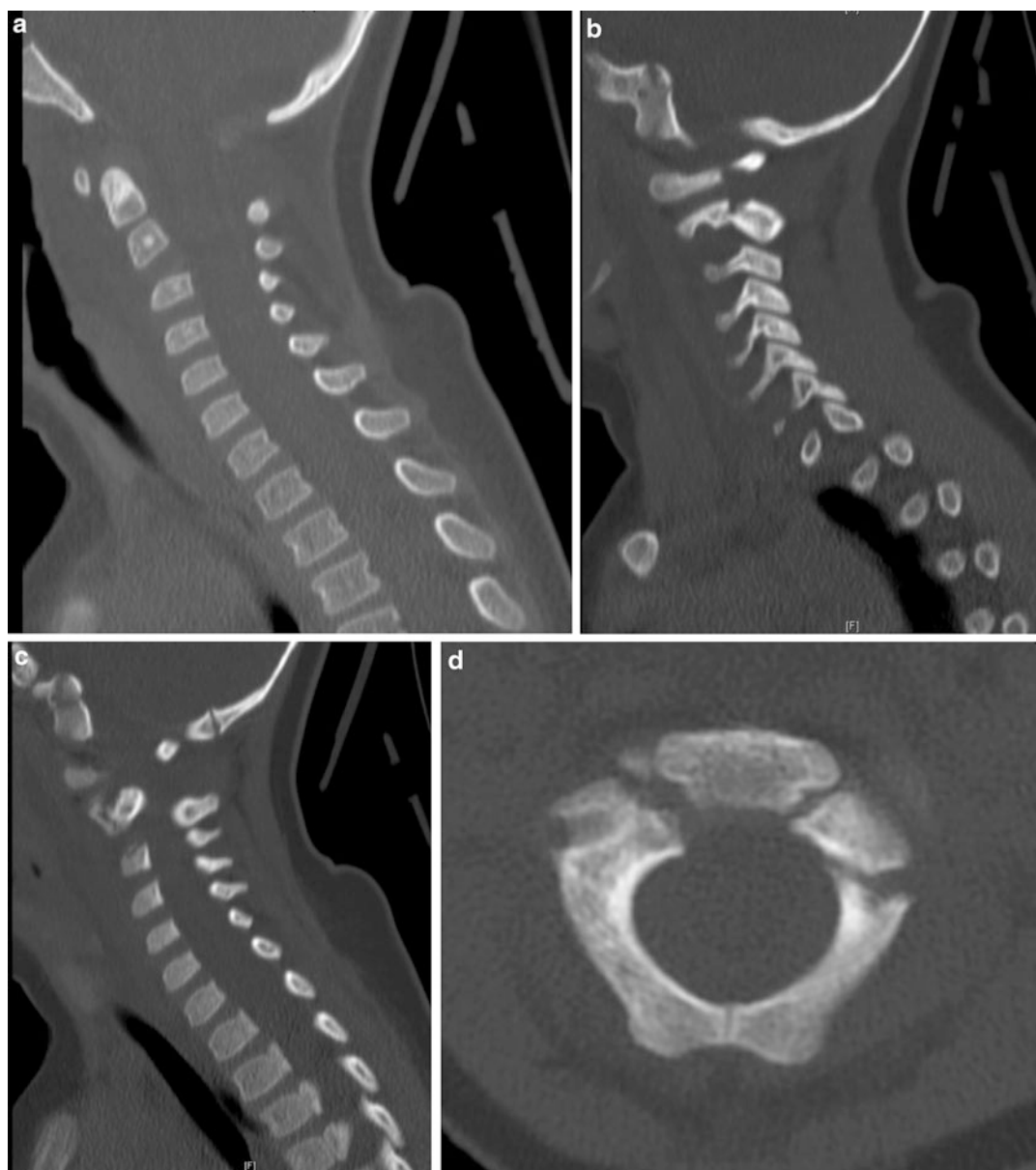


Fig. 1 Initial CT of the C-spine. (a) *Midsagittal* image revealing widening of the C2–C3 disk space with slight angulation. (b) *Right* parasagittal image revealing a *right* pedicle/laminar fracture at C2. (c) *Left*

parasagittal image revealing a *left* pedicle fracture at C2. (d) Axial image of C2 revealing bilateral pedicle fractures

3 Preoperative Problem List

- Traumatic C2–C3 spondylolisthesis in a 20-month-old patient
- Lack of good anterior column graft/support in this age range
- Healed and elongated pars and healed disk space limiting reduction
- Traumatic pseudomeningocele limiting reduction
- Bone destruction from pseudomeningocele
- Reliability of neuromonitoring in young patients

4 Treatment Strategy

The initial goal was to stabilize the patient's neck in a halo and attempt to reduce his subluxation, while undergoing neuromonitoring, to improve his alignment (Fig. 3). He underwent a preoperative MRI/MRA that revealed a pseudomeningocele (Fig. 4). Due to the pseudomeningocele, his neuromonitoring signals fluctuated while attempting closed



Fig. 2 Lateral C-spine X-ray 3 months after injury revealing C2–C3 subluxation with kyphosis and angulation



Fig. 3 CT 3 months after injury, midsagittal image revealing C2–C3 subluxation, kyphosis, and angulation

reduction. Therefore he was stabilized in his current position, with the intention of performing a planned open reduction and fusion. He underwent intraoperative reduction of the C2–C3 subluxation and C2–C5 fusion with C2 pars screws and sublaminar wiring at C4 and C5. The C3 laminae were too thin to accommodate wires, and the lateral masses were too

small to accommodate screws. His pseudomeningocele was decompressed, and a lumbar drain was placed to optimize wound healing. His reduction was limited by a presumed fused disk anteriorly. As he was neurologically intact with an improved overall alignment, also placing an anterior construct was considered difficult in this young of a child, the alignment was accepted (Fig. 5). He remained in a halo for 6 weeks and then was transitioned to a collar which was worn for 4 months. A CT at 6 months revealed bony fusion across all facet joints and lamina from C2 to C5 (Fig. 6). His collar was discontinued after flexion-extension imaging revealed no instability. He continued to do well neurologically, with resolution of his hyperreflexia.

5 Basic Principles

Traumatic spondylolisthesis of C2 is rare in the pediatric population but can be seen after motor vehicle accidents (MVA). A heightened sense of awareness must be maintained for upper cervical spine injuries in children, especially under the age of 2 due to the disproportionate head to body ratio.

C2 pedicle fractures have been seen in infants as young as 7 weeks of age. The mechanism is thought to be due to hyperextension and axial loading, similar to adults, with MVA being the leading cause. Typically patients are neurologically unharmed, as the fracture fragments separate, expanding the canal. The C2–C3 disk and posterior longitudinal ligament can be injured with severe injuries. These fractures can be missed on radiographs as the neural central synchondroses (which do not exhibit fusion until the age of 7) can mimic a fracture on oblique X-rays. Additionally, pseudosubluxation is commonly seen on lateral X-rays in children up to the age of 8.

Classification of these injuries was initially described by Effendi and further expanded by Levine and Edwards. There are five fracture patterns classically described in the adult literature. Type I are fractures through the pedicles without angulation and with minimal displacement. Type Ia are fractures with an elongation of the vertebral body, with little angulation or translation. Type II are fractures with significant angulation and displacement. Type IIa involves an oblique fracture line with significant angulation but minimal translation. Type III involves fractures with bilateral facet dislocations. In the adult literature, typically types I and Ia are managed with collars, types II and IIa require reduction and a halo vest, and type III require operative intervention. However in the pediatric population, management is unique to each patient as there is great variability regarding age, bone structure, the ability to tolerate a halo, and the need for custom orthoses. Similar to adults, typically these can be managed with a collar if there is no significant subluxation of C2 on C3. However if there is >3 mm of anterior

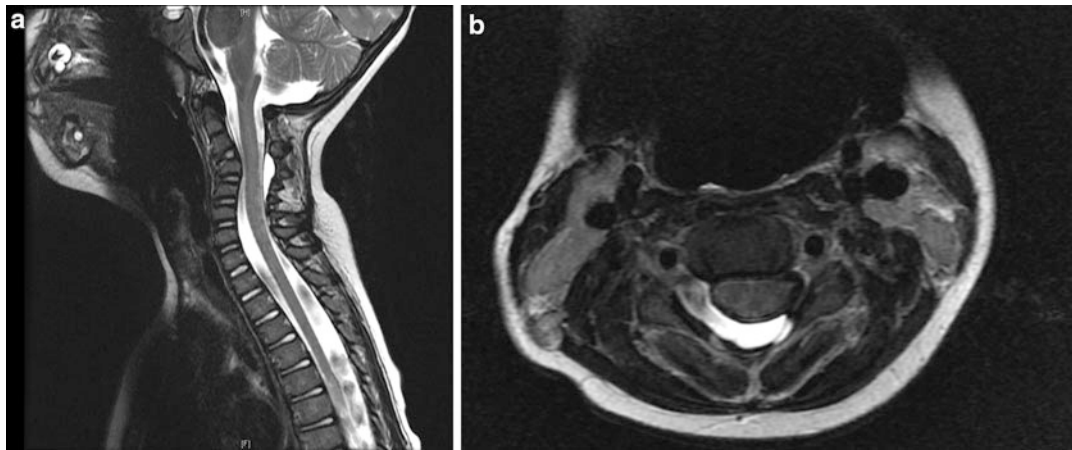
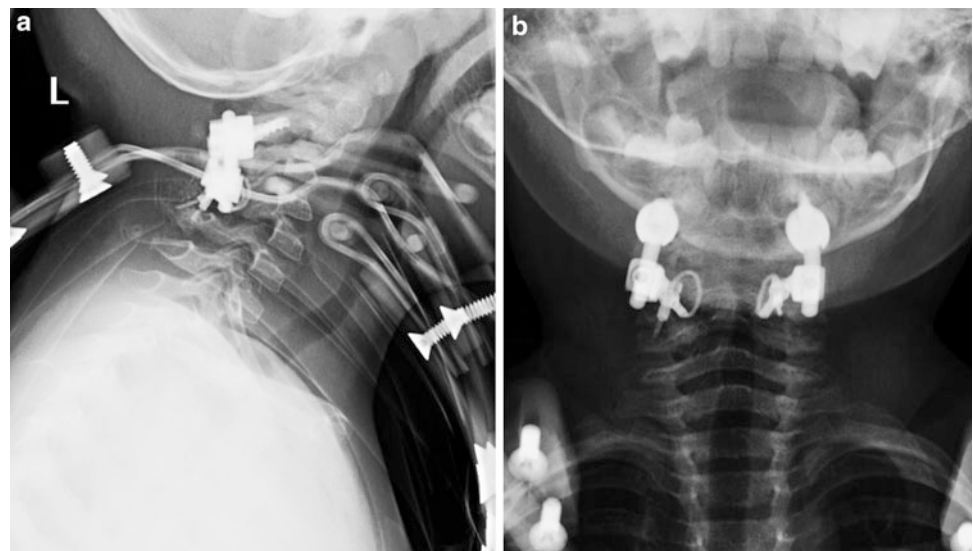


Fig. 4 Magnetic resonance image (MRI) of the C-spine 3 months after injury. **(a)** Midsagittal image revealing pseudomeningocele from C2–C3 to C4–C5 with previously described subluxation C2–C3. **(b)** Axial image at C3–C4 depicting the cord impingement from the pseudomeningocele

Fig. 5 Initial post-fusion radiographs. **(a)** Lateral C-spine X-ray revealing improved subluxation and implants. **(b)** Anteroposterior C-spine X-ray detailing implant placement



subluxation of C2 on C3, more rigid immobilization such as a halo may be appropriate.

6 Images During Treatment

See Fig. 5.

7 Technical Pearls

- Ensure a close and careful evaluation of the C-spine in children after motor vehicle accidents.
- Obtain a CT to assess the fracture and the ability of the bone to accommodate implants if fusion is warranted.
- Obtain an MRI to assess for disk and ligament injuries.
- Obtain an MRA to ensure no vascular compromise.
- Consider neuromonitoring with closed reduction of unstable fractures.
- If operative intervention is required, options include:
 - C2
 - Pars screws
 - Pedicle screws
 - Sublaminar wiring
 - Onlay bone graft
 - C3–C7
 - Lateral mass screws
 - Sublaminar wiring
 - Onlay bone graft

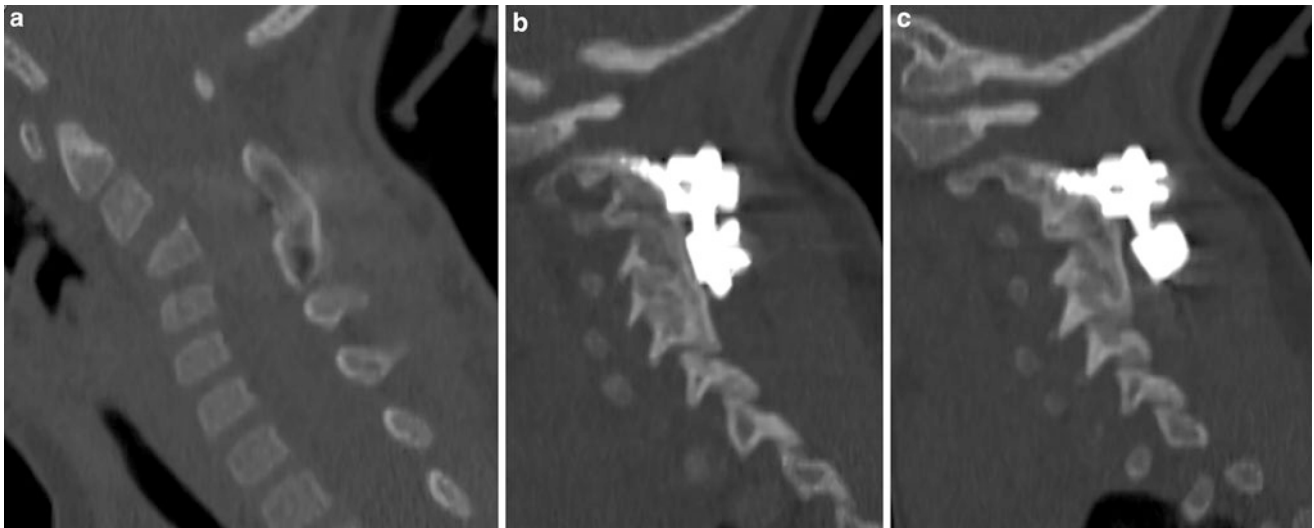


Fig. 6 CT C-spine 6 months postoperatively. (a) *Midsagittal* image revealing stable alignment and posterior fusion. (b) *Right parasagittal* image revealing bony fusion across facet joints C2–C5. (c) *Left parasagittal* image revealing bony fusion across facet joints C2–C5

8 Outcome Clinical Photos and Radiographs

See Fig. 6.

9 Avoiding and Managing Problems

- Consider custom orthoses for infants, as standard-sized halos can become dislodged.
- Evaluate implant options based on age of patient and the size of the spinal elements.
- Consider rigid orthoses after internal stabilization.

References and Suggested Readings

- Al-Mahfoudh R, Beagrie C, Woolley E, Zakaria R, Randon M, Clark S, Pillay R, Wilby M (2016) Management of typical and atypical hangman's fractures. *Global Spine J* 6(3):248–256
- Jackson RS, Banit DM, Rhyne AL, Darden BV (2002) Upper cervical spine injuries. *J Am Acad Orthop Surg* 10:271–280
- Lyon RM (2004) Pediatric spine injuries. In: Frymoyer JW, Wiesel SW (eds) *The adult & pediatric spine*, 3rd edn. Lippincott Williams & Wilkins, Philadelphia, pp 425–444
- Montalbano M, Fisahn C, Loukas M, Oskouian RJ, Chapman JR, Rs T (2017) Pediatric hangman's fracture: a comprehensive review. *Pediatr Neurosurg*. <https://doi.org/10.1159/000455923>



Unilateral Cervical Facet Fracture-Dislocation

Brian E. Kaufman, John A. Heydemann, and Suken A. Shah

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Abstract

While relatively rare in the young child, the incidence of subaxial cervical fractures and dislocations in children over 8 years of age approaches adult rates. Horizontally oriented facet joints and the lack of uncovertebral joints predispose the immature spine to increased motion in the sagittal and coronal planes, respectively. Unilateral facet dislocations result from combined flexion-distraction and rotatory forces which typically occur after motor vehicle

accidents or falls from heights. The presentation of these injuries can be subtle as children may complain only of neck pain. A careful physical examination is required to identify pretreatment neurologic deficits. Diagnosis is aided by advanced imaging studies, with Computed Tomography (CT) scans clearly delineating the bony injury while assisting in surgical planning. A pretreatment Magnetic Resonance Imaging (MRI) is recommended to evaluate for both disk herniation and injuries to the posterior ligamentous complex. Unilateral facet dislocations are characterized by a degree of rotational instability, with the axis of rotation centered around the intact contralateral facet. Persistent instability and worse long-term outcomes have been demonstrated with nonoperative treatment in the adult population. While closed reduction and prolonged external immobilization with a halo vest is possible, rigid internal surgical stabilization is preferred in the pediatric population. Solid arthrodesis is frequently attained and, in the absence of spinal cord injury, long-term outcomes are generally good.

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1 Brief Clinical History

The patient is a 14-year-old female gymnast who was performing a handstand on blocks five feet above ground level when she fell and sustained an axial loading injury to her head and neck. She reported a brief loss of consciousness but was able to ambulate immediately after the injury. She complained of subaxial neck pain, right arm soreness, and right thumb numbness. Neurologic evaluation revealed no motor deficits, mild paresthesias distally in the right C6 dermatome, and an absence of hyperreflexia or pathologic reflexes. She was placed into a cervical collar and advanced imaging was attained. CT findings were notable for a right-sided unilateral facet dislocation at C5–6 with 5 mm of anterior listhesis and fractures of the right C6 pedicle and lateral mass (Fig. 1a–d). MRI demonstrated effacement of the spinal cord at the level of injury without disk herniation. Disruption of the posterior longitudinal ligament was also noted (Fig. 2a–b).

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Unilateral facet fracture/dislocation at C5–6 with anterior listhesis, spinal cord effacement, and disruption of the posterior longitudinal ligament.
2. Right C6 paresthesias without motor deficits

4 Treatment Strategy

The primary aim of treatment in a unilateral facet fracture dislocation is to restore and maintain cervical alignment

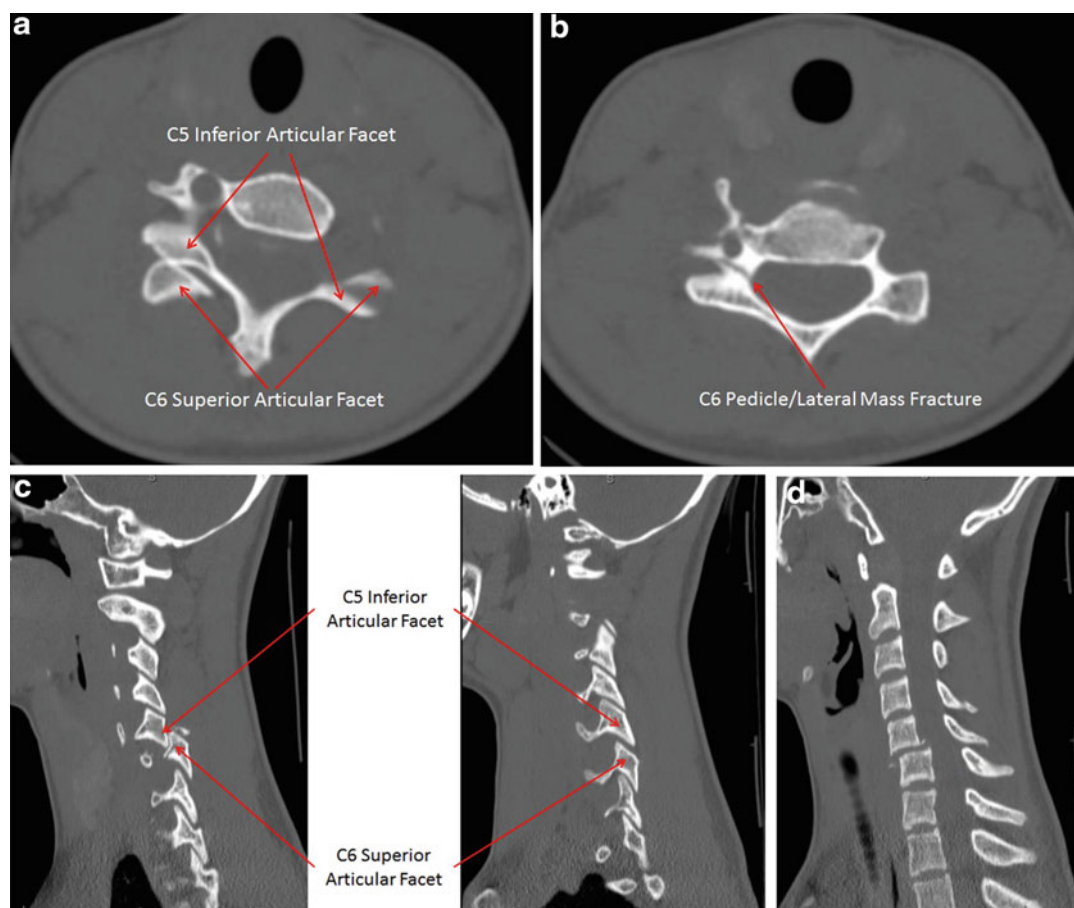
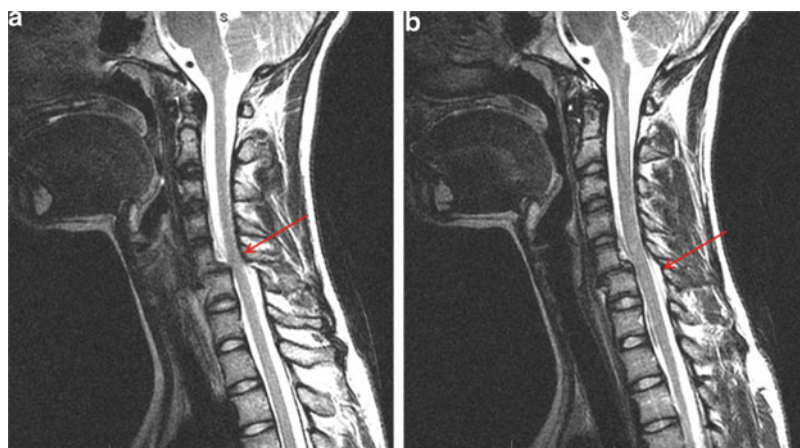


Fig. 1 (a) Axial image at level of C5–6 facet joints demonstrating anterior dislocation of right C5 inferior articular facet. (b) Axial image at level of C6 pedicle demonstrating right-sided pedicle and lateral mass

fractures. (c) Sagittal images demonstrating unilateral C5–6 facet dislocation. (d) Mid-sagittal image demonstrating anterior listhesis of C5 on C6

Fig. 2 Sagittal T2 images showing spinal cord effacement (**a**, arrow) and edema within the posterior longitudinal ligament, indicative of a ligamentous tear (**b**, arrow)



while minimizing trauma to the spinal cord and nerve roots. Unilateral facet injuries represent a spectrum ranging from a minimally displaced superior articular facet fracture to frank dislocation. Involvement of both the bony and discoligamentous structures of the cervical spine is common (Dvorak et al. 2007). In the adult population, considerable controversy exists regarding diagnosis, the timing and manner of reduction, and the optimal technique for post-reduction stabilization (Dvorak et al. 2007; Sellin et al. 2014). The incidence of cervical facet injury in children has rarely been reported in the literature and treatment paradigms are even less clear (Parada et al. 2010; Chen et al. 2013; Sellin et al. 2014).

Closed reduction in the neurologically intact, cooperative, adult patient via skull tongs and sequentially added weight has been described as safe (Kwon et al. 2006). Recently, however, nonoperative treatment of these injuries demonstrated worsening pain and disability scores on validated, disease-specific health related quality of life measures (Dvorak et al. 2007). These findings, in concert with biomechanical studies demonstrating persistent instability after closed reduction and external immobilization, have led to the recommendation for operative treatment with rigid internal fixation in the pediatric population (Sellin et al. 2014).

5 Basic Principles

Prior to undertaking treatment, the importance of performing and documenting a careful neurologic examination cannot be understated. When performing a reduction under anesthesia, neuromonitoring with somatosensory evoked potentials (SSEPs) and transcutaneous motor evoked potentials (tcMEPs) is mandatory. The potentials should be evaluated supine and then again after prone positioning. Application of a halo allows rigid control of the head with the ability to adjust alignment of the cervical spine intraoperatively.

Closed reduction is achieved via axial traction, initially in slight flexion, with movement to slight extension as serial lateral c-arm radiographs demonstrate facet alignment and subsequent reduction (Rathjen and Herring 2014).

Open reduction is indicated when closed reduction fails, in the presence of fracture-dislocations, and in the setting of neurologic compromise from disk herniations (Kwon et al. 2006). In the child, reduction can be safely performed through either an anterior or posterior approach (Sellin et al. 2014). Anteriorly, reduction is achieved after discectomy via distraction pins placed into the vertebral bodies. Arthrodesis with bone graft and plating is then performed. Posterior reduction can be performed via distraction across the spinous processes or laminae. Posterior arthrodesis with lateral mass screws, interlaminar wiring, lateral mass plates, or interlaminar clamps has all been successful (Kwon et al. 2006; Chen et al. 2013; Sellin et al. 2014). Postoperatively, immobilization in a rigid cervical orthosis for a minimum of 3 months is recommended with close clinical and radiographic follow-up to ensure maintenance of reduction.

6 Images During Treatment

See Fig. 3.

7 Technical Pearls

When performing a closed reduction in adults, many authors apply 10–15 pounds of weight for the head and then add 5–10 pounds of weight per level of injury (Kwon et al. 2006). It is important to note that safe weight limits have not been established in the pediatric population and application of halo traction weight should be dictated by surgeon experience and closely monitored with SSEPs and tcMEPs.

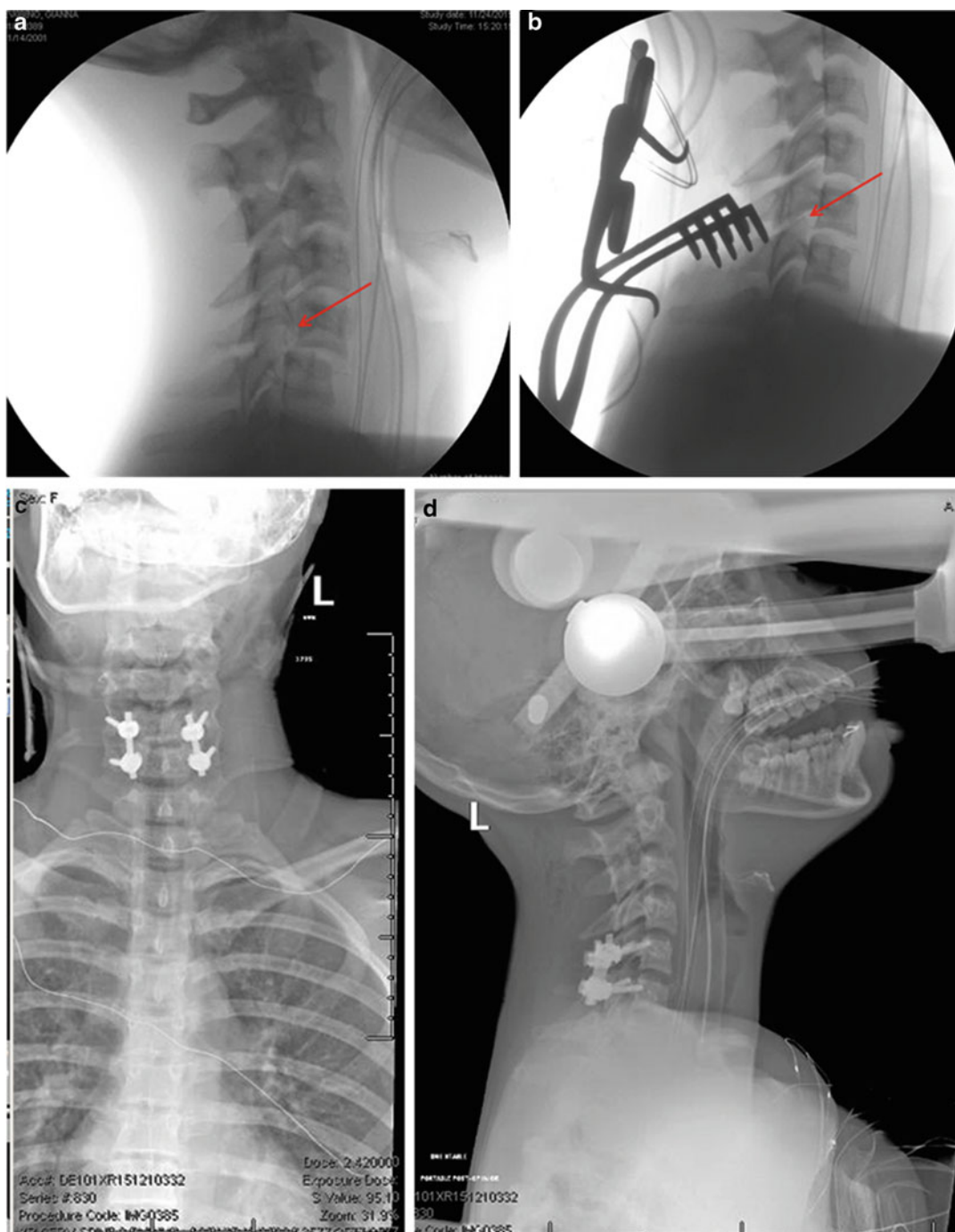
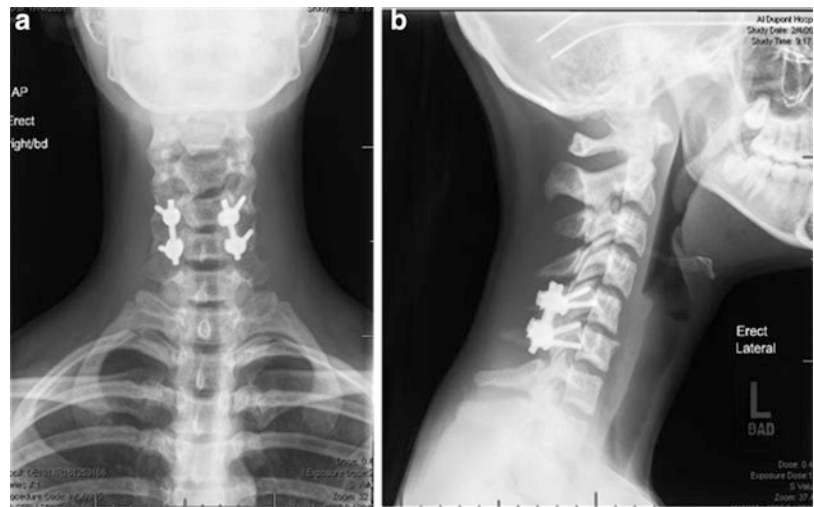


Fig. 3 Intraoperative images demonstrating a unilateral C5 facet dislocation pre-reduction (**a**, arrow) and post-reduction (**b**—arrow). Postoperative AP (**c**) and lateral (**d**) images after single level C5–6 posterior fusion with lateral mass screws

If difficulty is encountered when attempting an open posterior reduction, the superior articular facet can be burred away to help disengage the dislocated facets. This may increase instability once reduction is achieved (Kwon et al. 2006).

Lateral mass screw fixation can be safely performed in the pediatric population following the techniques established by either Roy-Camille or Magerl (Roy-Camille et al. 1989; Jeanneret et al. 1991).

Fig. 4 AP (a) and lateral (b) radiographs at 3 months postoperatively demonstrating early fusion mass consolidation and maintenance of facet reduction



8 Outcome Clinical Photos and Radiographs

See Fig. 4.

9 Avoiding and Managing Problems

The clinician should maintain suspicion for unilateral facet dislocations in children presenting with neck pain after high energy injuries characterized by flexion-distraction with or without rotational forces. Careful scrutinization of plain radiographs and the use of advanced imaging allow recognition of these injuries. The importance of neuromonitoring when performing reduction is critical to avoid intraoperative neurologic injury. Changes in SSEPs or tcMEPs should prompt the surgeon to evaluate for potential disk herniations or nerve root compression intraoperatively.

As demonstrated by the recent literature, rigid internal fixation with either anterior or posterior arthrodesis can be safely performed in the pediatric population, lessens the risk of post-reduction instability, and has superior clinical outcomes compared to nonoperative treatment (Dvorak et al. 2007; Sellin et al. 2014).

10 Cross-References

- Atlas Fractures
- Odontoid Fractures
- Pediatric Traumatic Spondylolisthesis of the Axis

References and Suggested Readings

- Chen Y, Wang X, Chen D, Liu X (2013) Surgical treatment for unilateral cervical facet dislocation in a young child aged 22 months old: a case report and review of the literature. *Eur Spine J* 22(Suppl 3): S439–S442
- Dvorak MF, Fisher CG, Aarabi B et al (2007) Clinical outcomes of 90 isolated unilateral facet fractures, subluxations, and dislocations treated surgically and nonoperatively. *Spine* 32(26): 3007–3013
- Jeanneret B, Magerl F, Ward EH, Ward JC (1991) Posterior stabilization of the cervical spine with hook plates. *Spine* 16(Suppl 3):S56–S63
- Kwon BK, Vaccaro AR, Grauer JN et al (2006) Subaxial cervical spine trauma. *J Am Acad Orthop Surg* 14:78–89
- Parada SA, Arrington ED, Kowalski KL, Molinari RW (2010) Unilateral cervical facet dislocation in a 9-year old boy. *Orthopedics* 33 (12):929
- Rathjen KE, Herring JA (2014) Spinal injuries. In: Herring JA (ed) *Tachdjian's pediatric orthopaedics*, 5th edn. Elsevier Saunders, Philadelphia, pp 1224–1244
- Roy-Camille R, Saillant G, Mazel C (1989) Internal fixation of the unstable cervical spine by a posterior osteosynthesis with plate and screw. In: *Cervical Spine Research Society (ed) The cervical spine*, 2nd edn. JB Lippincott, Philadelphia, pp 390–403
- Sellin JN, Shaikh K, Ryan SL et al (2014) Clinical outcomes of the surgical treatment of isolated unilateral facet fractures, subluxations, and dislocations in the pediatric cervical spine: report of eight cases and review of the literature. *Childs Nerv Syst* 30:1233–1242

Thoracic and Lumbar Compression Fractures

Brian E. Kaufman

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Abstract

Thoracolumbar spine fractures are relatively uncommon accounting for only 0.6–3% of all pediatric fractures. Mechanism dictates the injury pattern. Compression fractures typically occur as a result of axial loading from a fall. When the fall occurs with a forward flexed trunk, the majority of force is transmitted to the anterior column of the vertebral body. This force fractures the anterior column of the vertebral body and causes a wedge deformity. If the trunk is more extended, the vertebral body will be loaded more symmetrically, and the force through the body may be dissipated in a more radial fashion leading to a burst fracture. Careful physical examination is critical in these patients to rule out the possibility of neurologic involvement or associated injuries. Initial evaluation with anteroposterior (AP) and lateral supine x-rays is typically

sufficient to diagnose a compression fracture. If the diagnosis is in doubt, advanced imaging is helpful. Computerized tomography (CT) scans can confirm the presence of a suspected fracture. Magnetic resonance imaging (MRI) will show edema beneath the superior endplate, suggestive of an acute fracture, and also allows evaluation of the posterior ligamentous structures. In the absence of a significant kyphotic deformity, compression fractures are treated nonoperatively with a brief period of brace immobilization. In the pediatric population, the vertebral wedge deformity may reconstitute owing to the long-term remodeling potential of the vertebral body.

1 Brief Clinical History

A 10-year-old male sustained a fall off of the monkey bars landing directly on his backside. Immediately after the fall, he noted mid-thoracic back pain without radicular symptoms. He denied loss of consciousness or injury elsewhere. Upon examination, he was neurovascularly intact without motor or

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Fig. 1 (a–c) Injury presentation AP and lateral radiographs. The affected T7 vertebra is highlighted by the *red* arrow in (b) and (c). The sagittal index for the T7 vertebra was 0.810

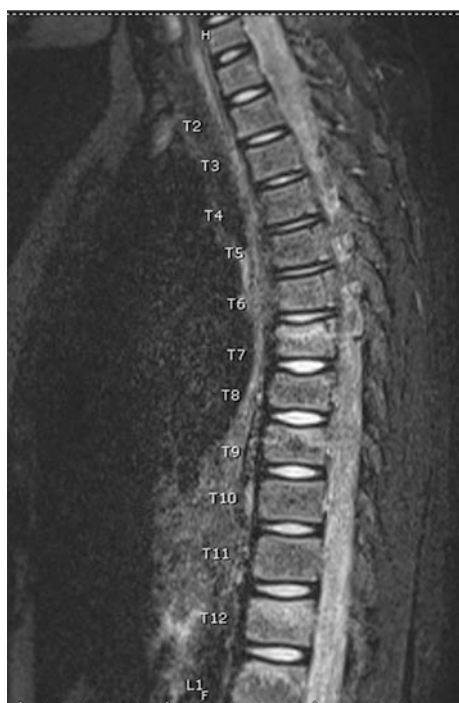
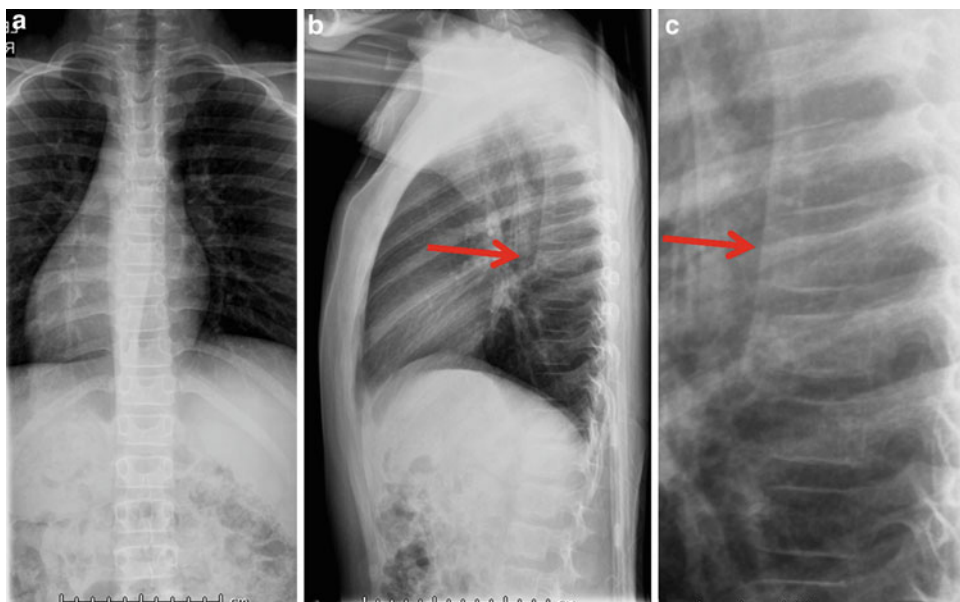


Fig. 2 Sagittal STIR MRI demonstrating edema beneath the superior endplate of T7 confirming the diagnosis of a compression fracture. No ligamentous involvement posteriorly is noted

sensory deficits. Bony tenderness to palpation in the mid-portion of the thoracic spine was present without obvious bony step-off. There was no interspinous tenderness. No pathologic reflexes were present. Initial radiographs

(Fig. 1a–c) demonstrated slight wedging of the superior endplate of T7 suggestive of a compression fracture. To confirm the suspected diagnosis, a non-contrast MRI of the neural axis was attained. Edema was noted under the superior endplate of T7 confirming the suspected diagnosis of a compression fracture (Fig. 2). The patient was admitted for pain control and fitting of an orthosis.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

T7 compression fracture with minimal wedging and loss of height.

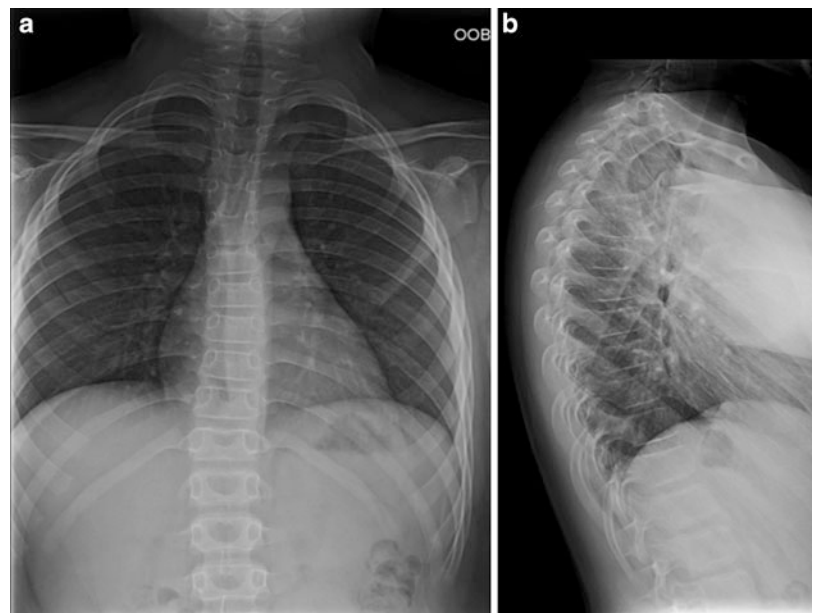
4 Treatment Strategy

In the pediatric population, compression fractures can almost universally be treated nonoperatively. The mainstay of treatment is immobilization with an orthosis and pain control. This patient was admitted to the hospital for pain control and fitting of a custom orthosis. In the past, the use of a



Fig. 3 Non-contrast CT scan of another patient who was in a motor vehicle collision and complained of thoracolumbar back pain. The CT scan demonstrates disruption of the superior endplates of the T11 and T12 vertebra with slight wedging of these vertebrae. The patient was diagnosed with two compression fractures and treated with a TLSO for 6 weeks

Fig. 4 (a–b) Upright AP (a) and lateral (b) x-rays 2 weeks after injury. These films were taken out of the TLSO. The degree of wedging at the T7 vertebra is unchanged from the initial injury films



hyperextension (Jewett-type) brace was commonplace. At the author's institution, children with simple compression fractures are placed into a custom-molded thoracolumbar spinal orthosis (TLSO) molded into slight extension. The child is permitted to ambulate freely with the brace and is discharged once pain is controlled. Owing to the stable nature of the fracture, the orthosis is not worn for sleeping.

The patient was advised to wear his TLSO for a total of 6 weeks. X-rays were taken at 2- and 6-week follow-up appointments to confirm that no additional kyphosis developed at the fracture site (Figs. 4a, b, and 5). At the 6-week visit, the patient was pain-free. Six additional weeks of activity restriction was recommended to allow definitive consolidation at the fracture site. Three months after his injury, the patient was returned to full activity without restriction.

5 Basic Principles

1. Compression fractures occur as the result of an axial loading injury to the spine with the trunk in flexion (Newton and Luhmann 2015). The higher water content of the nucleus pulposus in the immature spine allows the disc to act as more of a shock absorber thereby lessening the risk of bony injury (Akbarnia 1999).
2. By definition, only the anterior column of the vertebral body is involved in a compression fracture. This means the posterior portion of the endplate remains intact. The superior endplate will be involved twice as often as the inferior endplate. Even with 50% compression of the vertebral body, involvement of the posterior ligamentous structures is rare (Akbarnia 1999).



Fig. 5 Lateral x-ray at 6 weeks out of the TLSO demonstrates maintenance of the anterior height of T7 without interval wedging or kyphosis. The patient was pain-free at this visit, and the TLSO was discontinued

3. Compression of the vertebral body can occur in both the coronal and sagittal planes. Lateral compression causes a mild scoliosis that is stable and nonprogressive (McPhee 1981; Pouliquen et al. 1997).
4. The sagittal index as described by Gaca et al. can be used to distinguish a true compression fracture from the physiologic wedging often present in the thoracic and lumbar spines of children and adolescents (Gaca et al. 2010). These authors suggested that if the ratio of the height of the anterior portion of the vertebral body to the posterior portion was less than 0.893, the compression was unlikely to be physiologic. MRI (Fig. 2) and CT scans (Fig. 3) can be used to confirm a suspected compression fracture.
5. The goal of treatment is to prevent progression of the kyphotic deformity caused by the anterior wedging of the vertebral body. Fractures with less than 40° of acute wedging can be treated conservatively (Newton and Luhmann 2015).
6. The use of an orthosis for 6 weeks provides sufficient support for fractures amenable to conservative treatment. Either a TLSO or Jewett brace may be utilized (Akbarnia

1999; Newton and Luhmann 2015; Singer et al. 2016). Advising an additional 6 weeks of activity restriction after bracing prevents reinjury.

7. Fractures with substantial kyphotic deformity exceeding 40° at either a single level or across multiple levels can be treated with a posterior spinal fusion (Newton and Luhmann 2015).
8. The more skeletally immature the patient is at the time of injury, the greater the potential for remodeling of the vertebral body. Patients younger than 12 or those with a Risser sign less than 2 are likely to reconstitute the majority of their vertebral height over time (Magnus et al. 2003; Singer et al. 2016). Some authors have suggested that disruption of the vertebral end plate may lead to early disc degeneration, the significance of which is not known (Kerttula et al. 2000).

6 Images During Treatment

See Fig. 4.

7 Technical Pearls

1. The level of the fracture should determine the type of orthosis utilized. Fractures at the T6 level and above require extension of the brace to include the cervical spine (CTLTO or Minerva-type brace) in order to provide adequate immobilization. Thoracic compression fractures from T7 distally and lumbar fractures may be treated with a TLSO. Isolated lumbar compression fractures can be treated in a lumbosacral orthosis (LSO).
2. Molding the TLSO into slight extension at the fracture site may provide additional pain relief and theoretically guards against worsening of an acute kyphotic deformity.
3. The author typically takes upright spine x-rays out of the brace 2 weeks after injury. Given the inherent stability of a compression fracture, removing the brace briefly for the x-ray is acceptable and allows better imaging of the affected vertebra.
4. Full-length scoliosis films are preferred when evaluating these injuries to allow for adequate determination of sagittal balance.

8 Outcome Clinical Photos and Radiographs

See Figs. 5 and 6.

Fig. 6 (a–c) AP (a) and lateral (b) x-rays of a 17-year-old male who presented to the clinic with the insidious onset of mid-thoracic back pain without recent trauma. No neurologic symptoms were present. In the absence of trauma, the presence of an apparent compression fracture at T6 was concerning. MRI (c) revealed a pathologic burst fracture at T6 with focal kyphosis. No substantial spinal cord compression was noted. Increased signal was seen in the T10–T12 vertebra. Further workup revealed the presence of multiple metastatic lesions throughout the body. The patient was ultimately diagnosed with metastatic alveolar rhabdomyosarcoma after biopsy of a pelvic lesion



9 Avoiding and Managing Problems

1. Patients with multiple consecutive compression fractures are at a higher risk for developing a kyphotic deformity. Consideration should be given to monitoring these patients more frequently with radiographs or extending the duration of bracing.
2. Activity restriction for 6 weeks after discontinuation of bracing lessens the risk of reinjury. Upon diagnosis, all patients in the author's practice are advised of the need for a total of 3 months of activity restriction.
3. The presence of a compression fracture in the absence of significant axial trauma should raise suspicion. Multiple compression fractures can be a sign of underlying osteopenia, infection, or neoplasm (Fig. 6a–c). Additional imaging modalities and laboratory studies are often required in these cases.

10 Cross-References

- [Spinal Cord Injury Without Radiographic Abnormalities \(SCIWORA\)](#)

References and Suggested Readings

- Akbarnia BA (1999) Pediatric spine fractures. *Ortho Clin N Am* 30(3):521–536
- Gaca AM, Barnhart HX, Bisset GS (2010) Evaluation of wedging of lower thoracic and upper lumbar vertebral bodies in the pediatric population. *AJR* 194(2):516–520
- Kerttula LI, Serlo WS, Tervonen OA et al (2000) Post-traumatic findings of the spine after earlier vertebral fractures in young patients. *Spine* 25(9):1104–1108
- Magnus KK, Anders M, Ralph H et al (2003) A modeling capacity of vertebral fractures exists during growth – an up to 47-year follow-up. *Spine* 28(18):2087–2092
- McPhee IB (1981) Spinal fractures and dislocations in children and adolescents. *Spine* 6(6):533–537
- Newton PO, Luhmann SJ (2015) Thoracolumbar spine fractures. In: Flynn JM, Skaggs DL, Waters PM (eds) *Rockwood and wilkins fractures in children*, 8th edn. Wolters Kluwer Health, Philadelphia, pp 901–919
- Pouliquen JC, Kassis B, Glorion C, Langlais J (1997) Vertebral growth after thoracic or lumbar fracture of the spine in children. *J Pediatr Orthop* 17(1):115–120
- Singer G, Parzer S, Casatellani C et al (2016) The influence of brace immobilization on the remodeling potential of thoracolumbar impaction fractures in children and adolescents. *Eur Spine J* 25:607–613

Sacral Aneurysmal Bone Cyst

Chase C. Woodward, Patrick Cahill, and Alex Arkader

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Abstract

A 14-year-old boy presented with 2 months of persistent low back pain and right leg weakness after a baseball slide. Following an imaging work-up, a large cystic lesion was found in the upper sacrum, impinging upon the descending right sacral nerve roots, suggestive of an aneurysmal bone cyst. Given the patient's presentation with a neurological deficit, he was expeditiously scheduled for surgical management. The day prior to surgery, selective embolization was performed to minimize possible intraoperative bleeding. Surgical decompression of the neural elements was followed by biopsy and intraoperative frozen section for diagnosis confirmation. The aneurysmal bone cyst was then excised, the cavity

was ablated with a high-speed bur and electrocautery prior to bone grafting, and the involved spinal segment was stabilized. Postoperatively, the patient had improved pain and neurological function, and he remained free of recurrence 1 year following the index procedure.

1 Brief Clinical History

A 14-year-old previously healthy boy presented with 2 months of low back pain and right leg weakness after a slide into the home plate during a baseball game. He initially underwent conservative treatment with physical therapy, but his symptoms persisted, which prompted referral for orthopedic evaluation. The pain was intermittent, sharp, and mainly in the right lower back, with radiation to the right gluteal region. He reported some numbness in the right lateral calf and foot. The patient denied saddle anesthesia, urinary or bowel changes, fevers, weight loss, or night pain.

On examination, the patient was well appearing and stood with normal spinal balance. An antalgic gait favoring the right lower extremity was noted. Inspection of the spine

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was remarkable for a dimple over the sacrum and fullness to palpation over the right lumbosacral junction. Neurological examination showed 4/5 strength of right ankle dorsiflexion and plantarflexion, decreased sensation in the right lateral calf and foot, and an absent right Achilles reflex. The contralateral extremity had normal strength, sensation, and reflexes. There was an absence of clonus and Babinski signs bilaterally.

Initial x-rays of the lumbosacral spine demonstrated a well-defined lytic lesion in the upper sacrum. Given the radiographic findings in the setting of a neurological deficit, an MRI was obtained which demonstrated an expansile lesion predominantly at the S1 and S2 posterior elements, extending to the anterior aspect of the sacrum through the right-sided pedicles, and compressing the surrounding neural elements. There were multiple fluid levels within the lesion but no soft tissue mass, which are findings suggestive of an aneurysmal bone cyst (ABC). Arrangements were made for an expedited biopsy and definitive treatment including pre-operative vascular embolization followed by neural decompression, tumor excision, and an instrumented fusion.

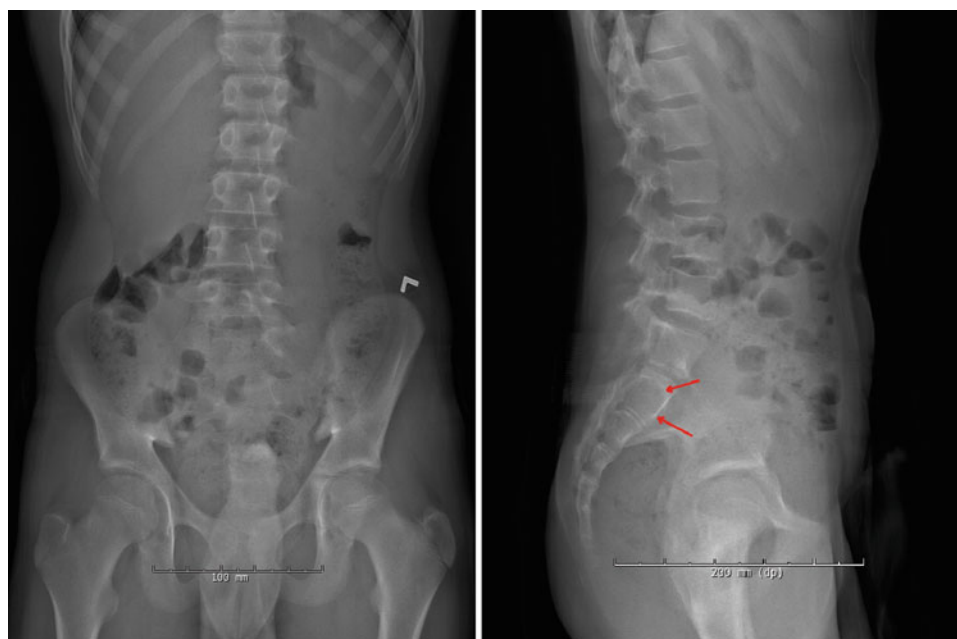
2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

1. Aneurysmal bone cyst at the S1 and S2 levels

Fig. 1 Standing AP and lateral radiographs of the lumbosacral spine. There are findings of lumbarization of the S1 vertebra. A subtle lytic lesion is seen within the S2 vertebral body and corresponding posterior elements (marked by *arrows* on the lateral view). There is expansion of the lesion beyond the posterior cortex of the S2 vertebral body, a characteristic finding of aneurysmal bone cysts



2. Compression of the right-sided L5, S1, and S2 nerve roots with neurological deficit
3. Potential spinopelvic instability following tumor excision
4. Postoperative surveillance for tumor recurrence

4 Treatment Strategy

A patient who presents with new-onset back pain and a neurological deficit on examination should raise suspicion for underlying spinal pathology and warrants an expeditious diagnostic work-up. In this case, an episode of low-energy trauma (i.e., a baseball slide) led to the diagnosis of a large upper sacral tumor.

Aneurysmal bone cysts (ABCs) are benign osseous tumors that have the potential to be locally aggressive. ABCs are characteristically blood-filled and expansile lesions, seen throughout the axial and appendicular skeleton, consisting of dilated, thin-walled vascular spaces not lined by an identifiable endothelium. In general, benign primary spine tumors are very rare accounting for about 1% of all primary skeletal tumors, and of this small group, ABCs are one of the more commonly seen tumor types. They occur most commonly in the second decade of life, and there is usually a delayed diagnosis after the onset of new back pain. In some instances, the patient will also have a neurological deficit due to compression of the neural elements. Radiographs are difficult to evaluate but can show lytic, cystic changes to the involved vertebrae. MRI has significantly better sensitivity and can demonstrate multilocular lesions with low signal on T1-weighted sequences and high signal on T2-weighted sequences, with the classic finding of multiple fluid levels.

Fig. 2 Representative right parasagittal images from a T1- and T2-weighted MRI sequence acquired in the supine position. There is a large, heterogeneous cystic lesion infiltrating the bodies and posterior elements of primarily the S1 and S2 levels. Characteristic of an aneurysmal bone cyst, the lesion has a low signal intensity on the T1 sequence and high signal intensity on T2, and multiple fluid levels are seen on the T2 sequence

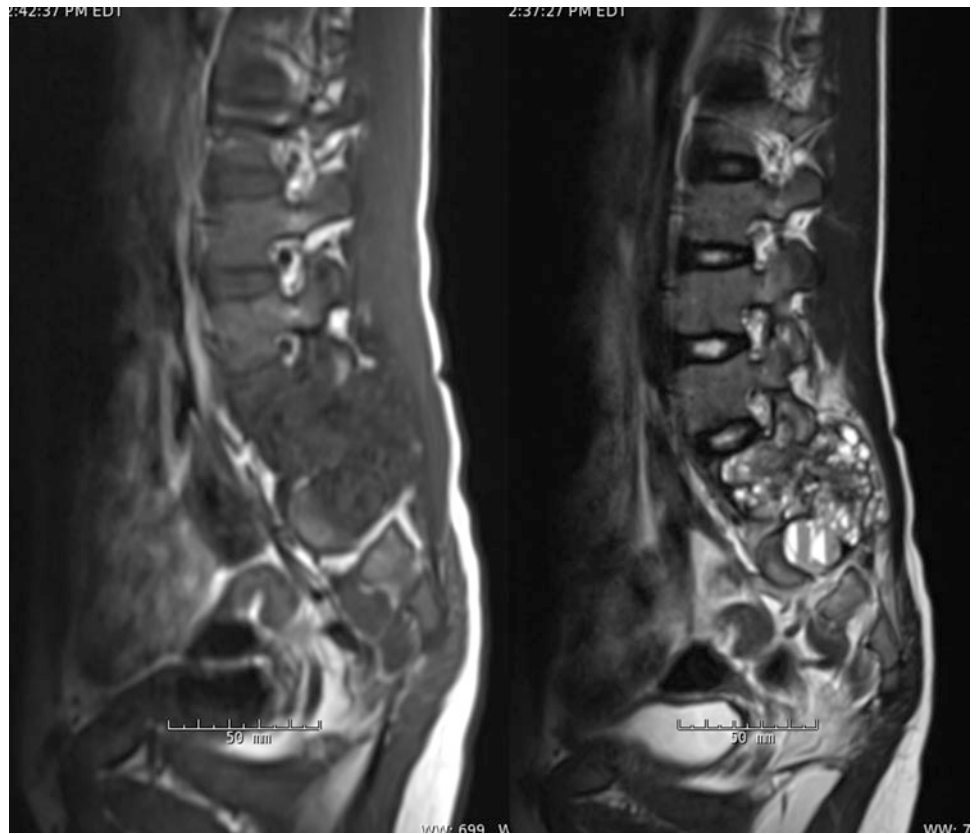
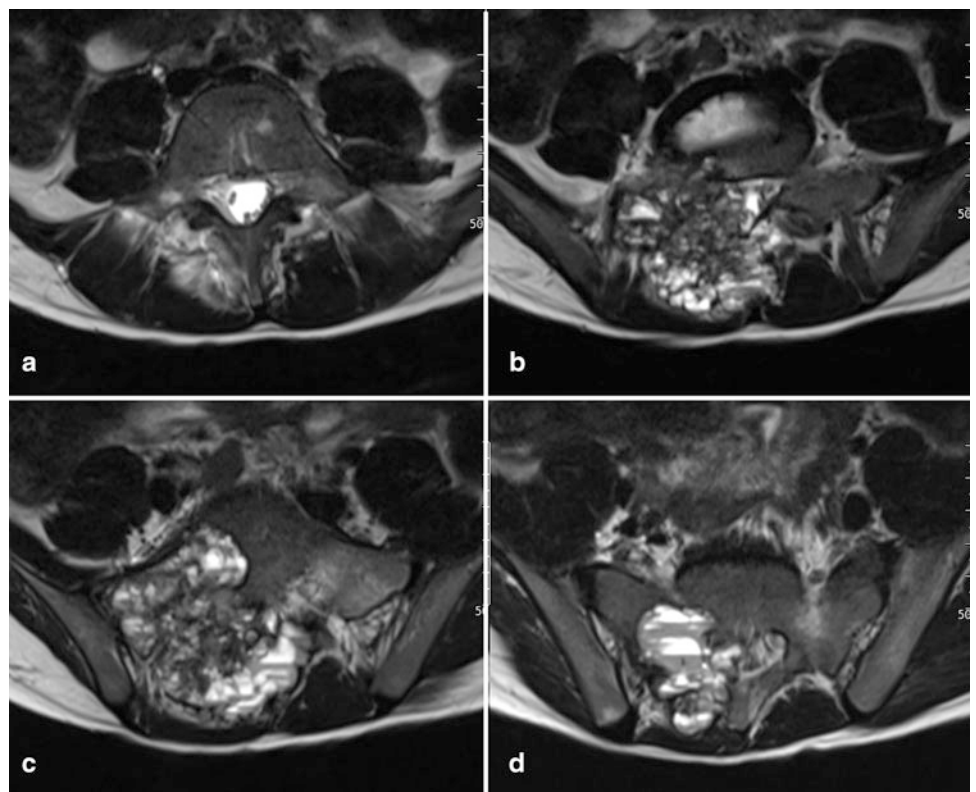


Fig. 3 Selected axial images from the T2-weighted MRI sequence through the L5 level (a), L5/S1 interspace (b), S1 level (c), and S2 level (d). Again, a large heterogeneous cyst involving primarily the right S1 and S2 levels is seen, with the lesion slightly crossing the midline in the central canal and posterior elements. The lesion involves the majority of the right sacral ala and closely abuts the sacroiliac joint (c). The right-sided exiting L5 nerve root and descending sacral nerve roots appear compressed. The L5-S1 disk is relatively spared (b) which is characteristic of a spinal ABC, and again the classic finding of multiple fluid levels is clearly seen at the S2 level (d)



Most often, ABCs are located in the posterior elements of the spinal column, but they can expand into the vertebral body, sometimes involving multiple levels with characteristic sparing of the intervertebral disk space. There are no specific laboratory tests for the diagnosis.

This 14-year-old boy had a history and imaging findings suggestive of a sacral ABC at the S1 and S2 levels with compression of the adjacent right L5, S1, and S2 nerve roots. The treatment plan included decompression of the neural elements, biopsy for a definitive diagnosis, tumor excision and ablation of the tumor cavity, and stabilization of the involved spinopelvic segment. Given the high vascularity of ABCs, preoperative selective arterial embolization was performed by the interventional radiology team to reduce intraoperative bleeding. Thereafter the orthopedic spine and neurosurgical teams proceeded with exposure and decompression of the neural elements. Intraoperative neuromonitoring was used to minimize the risk of any iatrogenic neurological injury. A frozen tissue biopsy was sent intraoperatively to confirm the diagnosis of ABC prior to proceeding with intralesional tumor excision. After a meticulous excision, the remaining tumor bed was ablated with a high-speed bur and electrocautery and then filled with a combination of allogenic graft putty and cancellous bone chips. Finally, the stability of the spine and pelvis was evaluated intraoperatively to determine the best construct for fixation. Specifically, during preoperative planning, the proximity of the lesion to the right sacroiliac joint was concerning because tumor excision might create spinopelvic instability. Fixation options included an all posterior construct with pedicle screws and sacral alar-iliac screws or, if necessary, placement of an interbody graft for additional stability and a larger fusion area.

5 Basic Principles

1. Aneurysmal bone cysts are benign osseous tumors that can occur in the spine and have the potential to be locally aggressive. These tumors do not spontaneously resolve, so most symptomatic patients undergo some form of treatment, with options including pharmaceutical agents, embolization, sclerotherapy, radiation, or surgical excision.
2. MRI is often useful for the diagnosis of ABCs and allows the surgeon to define the involved anatomy, and its relationship to the surrounding soft tissues including the neural elements of the spine.
3. The surgeon must carefully consider the differential diagnosis when managing a musculoskeletal tumor. Specifically in the setting of an expansile cystic lesion the surgeon must rule out a telangiectatic osteosarcoma, a rare malignant osseous tumor, which may have a similar

appearance to an ABC on MRI. Prior to definitive excision of an ABC, the tissue diagnosis is mandatory. This can be achieved in a separate biopsy procedure or during the surgical resection with biopsy and frozen section. If the tissue diagnosis is unclear, definitive treatment should be delayed.

4. Preoperative selective arterial embolization of vascular tumors can significantly reduce intraoperative bleeding and should be considered prior to spinal ABC excision.
5. Central canal and neural foramen decompression should be performed as necessary based upon preoperative symptoms, MRI findings, and intraoperative signs of stenosis.
6. To reduce the risk of ABC recurrence, an intralesional resection with extended margins should be performed (en bloc resection is often not possible due to the complex neuroanatomy of the spine). After careful curettage, adjuvants such as argon beam coagulation, high-speed burring, cementation, or phenol application are indicated.
7. The surgeon must carefully consider the possibility of spinal instability following tumor excision, especially in the setting of large ABCs, multilevel lesions, involvement of more than one spinal column, or significant resection of the facet joints or ligamentous structures. The resulting tumor cavity should be filled with bone graft, and instrumentation should be used as necessary to span any segment of instability.
8. Recurrence rates for ABCs can be high. Larger studies in the literature show a range of 7–42% recurrence rate following excision and use of various adjuvants (Bollini et al. 1998; de Kleuver et al. 1998; Dormans et al. 2004; Erol et al. 2015; Gibbs et al. 1999; Ozaki et al. 1996; Vergel De Dios et al. 1992). For this reason, regular postoperative surveillance and imaging is needed to monitor for tumor recurrence. Most authors recommend 2 years of postoperative surveillance. In case an MRI is needed, titanium implants are preferable to stainless steel because of the lower metal artifact. (Torpey et al. 1995).

6 Images During Treatment

See Fig. 4.

7 Technical Pearls

1. Preoperative selective arterial embolization of the vascular supply to the ABC may decrease intraoperative bleeding. The interval between embolization and tumor resection should be short, generally less than 48 h. In this case, the patient was admitted the day prior to surgery for embolization by an interventional radiology team.

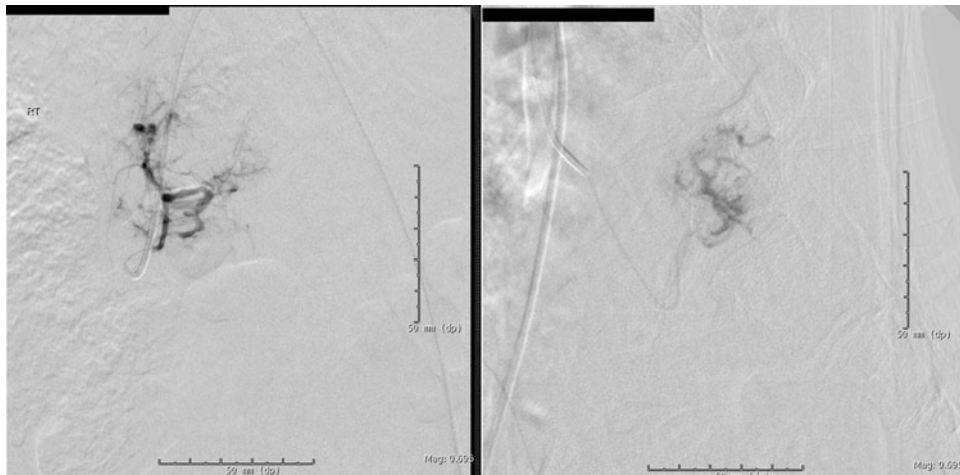
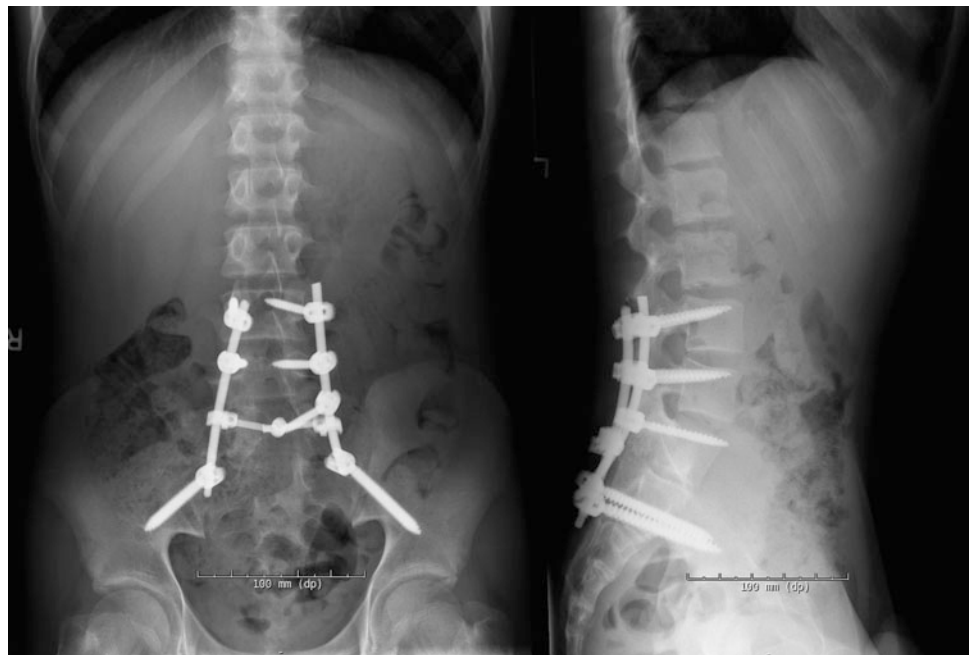


Fig. 4 AP and lateral fluoroscopic images of the sacral spine obtained during digital subtraction angiography. A tumoral blush is appreciated in the right lumbosacral region immediately after contrast dye injection. A microcatheter was passed retrograde through the left common femoral

artery into the lower abdominal aorta and subsequently guided into the right internal iliac artery. The iliolumbar artery was accessed, and small arteries feeding the tumor were successfully embolized with polyvinyl alcohol particles

Fig. 5 Postoperative standing AP and lateral radiographs of the lumbosacral spine. There is evidence of laminectomies at the L5, S1, and S2 levels, pedicles screws at the L4, L5, and S1 levels, and S2-alar-iliac screws distally



2. Intraoperative neuromonitoring should be utilized when the neural elements are at risk of iatrogenic injury (i.e., decompression, instrumentation, or deformity correction).
3. The surgeon should obtain a tissue sample (e.g., intraoperative frozen biopsy sent for a pathologist's review) to confirm the diagnosis of ABC prior to definitive intralesional resection.
4. Multilevel spinal ABCs typically do not expand into the intervertebral disk space. In this case the L5-S1 and S1-S2 intervertebral spaces were preserved which provided important landmarks during the tumor resection.
5. After complete tumor resection the resulting cavity was ablated with a combination of high-speed burring and electrocautery; other adjuvants have also been described. Subsequently the cavity should be packed with bone graft.
6. The tumor's large size and close proximity to the right sacroiliac joint was carefully considered during preoperative planning. Due to concerns for possible sacro-pelvic instability, S2-alar-iliac screws were used for fixation at the distal end of the construct. This technique of spinopelvic fixation has the advantage of being low profile, offers direct connection to rods seated in the more

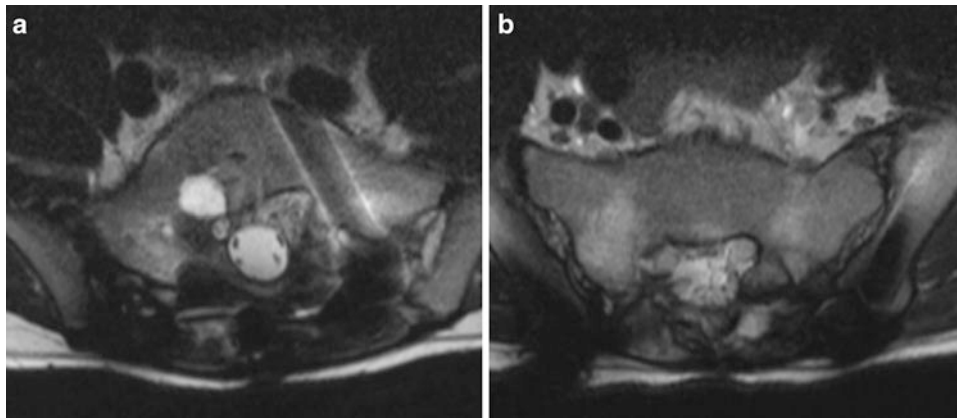


Fig. 6 This MRI was obtained 1 year postoperatively to monitor for tumor recurrence. Images from the axial T2 sequence are shown at the S1 level (**a**) and S2 level (**b**). A small area of cystic change is seen in the S1 vertebral body which has been stable on serial imaging, but

otherwise the bone graft has been incorporated where the ABC was excised. No compression of the neural elements is appreciated. Metal artifact can be seen from the left S1 pedicle screw and bilateral S2-alar-iliac screws

proximal pedicle screws (i.e., no need for offset connectors often required for traditional iliac screws), and excellent biomechanical strength.

7. The posterior instrumentation construct was evaluated intraoperatively for stability by applying force to the screws and compressing the pelvis. If there was any suspicion of ongoing instability in the spinal column, structural bone graft could be used for an interbody fusion, and if necessary, spinopelvic fixation could be augmented with additional iliac screws.
8. When the normal spine anatomy has been significantly distorted (e.g., in the setting of a destructive tumor or severe deformity) consider the use of intraoperative navigation for the placement of instrumentation.
9. Titanium implants are preferable to stainless steel due to reduced metal artifact on postoperative surveillance MRI.

4. When excising tumors involving the spinal column, intraoperative neuromonitoring should be utilized to reduce the risk of iatrogenic neurological injury.
5. The spine surgeon must carefully evaluate the involved anatomy and the consequences of tumor resection on spinal stability. If postoperative instability is a concern, the surgeon should instrument the involved segment with the goal of fusion. Titanium implants are preferable to steel because there is less metal artifact on surveillance MRI.
6. There is a significant recurrence rate following excision of ABCs. To reduce the risk of recurrence, the tumor cavity should be mechanically and/or chemically ablated and thereafter packed with bone graft. Following surgery, the patient should undergo regular imaging to monitor for recurrence.

8 Outcome Clinical Photos and Radiographs

See Figs. 5 and 6.

9 Avoiding and Managing Problems

1. A patient presenting with new-onset back pain and a neurological deficit should raise suspicion for underlying spinal pathology.
2. Confirming the diagnosis of ABC prior to treatment is critically important. The presentation and imaging can appear similar to a telangiectatic osteosarcoma.
3. ABCs are highly vascular lesions. Surgical blood loss may be limited by preoperative selective arterial embolization.

References and Suggested Reading

- Arkader A, Dormans JP (2010) Pathologic fracture associated with tumors and unique conditions of the musculoskeletal system. In: Beaty JH, Skaggs DL, Flynn JM, Waters K (eds) Rockwood and Wilkins' fractures in children, Seventh edn. Lippincott Williams & Wilkins, Philadelphia, pp 120–191
- Arkader A, Tolo VT (2010) Primary bone tumours of the growing spine. *Orthop Trauma* 24:346–354
- Bollini G, Jouve JL, Cottalorda J et al (1998) Aneurysmal bone cyst in children: analysis of twenty-seven patients. *J Pediatr Orthop B* 7:274–285
- Boriani S, De Iure F, Campanacci L et al (2001) Aneurysmal bone cyst of the mobile spine: report on 41 cases. *Spine (Phila PA 1976)* 26:27–35
- Chang TL, Sponseller PD, Kebaish KM, Fishman EK (2009) Low profile pelvic fixation: anatomic parameters for sacral alar-iliac fixation versus traditional iliac fixation. *Spine (Phila PA 1976)* 34:436–440
- Dormans JP, Hanna BG, Johnston DR et al (2004) Surgical treatment and recurrence rate of aneurysmal bone cysts in children. *Clin Orthop Relat Res* 421:205–211

- Erol B, Topkar MO, Caliskan E, Erbolukbas R (2015) Surgical treatment of active or aggressive aneurysmal bone cysts in children. *J Pediatr Orthop B* 24:461–468
- Gibbs CP Jr, Hefele MC, Peabody TD et al (1999) Aneurysmal bone cyst of the extremities: factors related to local recurrence after curettage with a high-speed burr. *J Bone Joint Surg* 81:1671–1678
- de Kleuver M, van der Heul RO, Veraart BE (1998) Aneurysmal bone cyst of the spine: 31 cases and the importance of the surgical approach. *J Pediatr Orthop B* 7:286–292
- Ozaki T, Hillmann A, Lindner N, Winkelmann W (1996) Aneurysmal bone cysts in children. *J Cancer Res Clin Oncol* 122:767–769
- Richard JT (2010) Embolization of musculoskeletal bone tumors. *Semin Intervent Radiol* 27:111–123
- Thakur NA, Daniels AH, Schiller J et al (2012) Benign tumors of the spine. *J Am Acad Orthop Surg* 20:715–724
- Torpey BM, Dormans JP, Drummond DS (1995) The use of MRI-compatible titanium segmental spinal instrumentation in pediatric patients with intraspinal tumor. *J Spinal Disord* 8:76–81
- Vergel De Dios AM, Bond JR, Shives TC, McLeod RA, Unni KK (1992) Aneurysmal bone cyst: a clinicopathologic study of 238 cases. *Cancer* 69:2921–2931

Management of Pediatric and Adolescent Thoracolumbar Burst Fractures

José Ramírez, Heather Hansen, and Craig Eberson

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Abstract

Thoracolumbar burst fractures are relatively uncommon in the pediatric and adolescent populations. Older children who engage in high-risk activities are more likely to sustain these injuries. Burst fractures are caused by axial compressive forces that drive the intervertebral disc through the vertebral endplate thereby fracturing the body and disrupting both the anterior and middle columns of the thoracolumbar spine. These fractures deserve careful consideration, and at times, surgical intervention, given their potential to cause significant

neurological injury and disability. This chapter defines stable and unstable injuries of the thoracolumbar spine and outlines the indications for surgical management of burst fractures. We present a rationale for level selection while performing a posterior spinal instrumentation, and we share the techniques employed in order to achieve fracture reduction and decompression of the involved neurological elements.

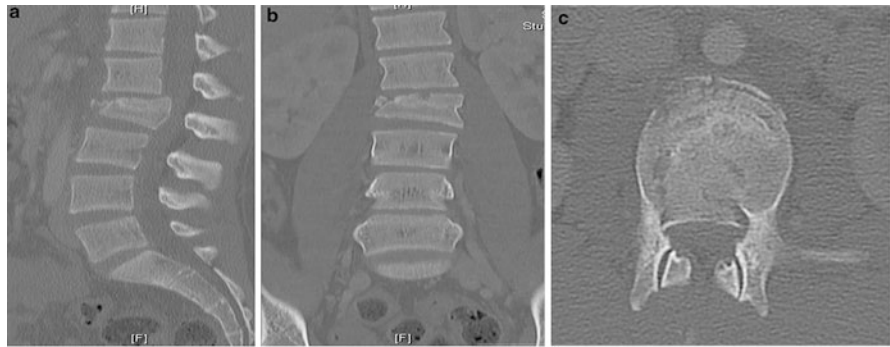
1 Brief Clinical History

A 16-year-old female presented in the emergency department after a motor vehicle collision. On examination she complained right-sided thigh pain and was noted to have knee extensor weakness, and bilateral lower leg paresthesias. Rectal tone and sensation were preserved. Imaging demonstrated an L2 burst fracture. Operative intervention was chosen due to mechanical instability of the fracture as well as neurologic symptoms. Immediately post-operatively, her paresthesias resolved, yet she still demonstrated 4/5 strength in

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Fig. 1 CT scan of lumbar spine demonstrating significant relative sagittal kyphosis (a), coronal deformity (b), and bony retropulsion (c) of an L2 burst fracture



the right L3 nerve root. At 1-year post-op, she had full recovery of her motor function. Radiographs demonstrated maintenance of her sagittal and coronal alignment.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

Unstable lumbar burst fracture with neurological injury.

4 Treatment Strategy

Burst fractures are uncommon in the pediatric population but can lead to significant morbidity. These injuries can be associated with abdominal as well as head injuries in 42% and 30% of cases, respectively. Thus, evaluation of these patients must be dictated by Advanced Trauma Life Support (ATLS) protocols. A motor and sensory examination by dermatome should be performed. Additionally, the examiner should palpate and inspect the entire spine for the presence of step-offs, tenderness, ecchymosis, or evidence of open fractures. Such findings have been shown to be up to 87% sensitive and 75% specific for detecting thoracolumbar spine fracture. When spinal trauma is suspected, plain radiographs of the entire spine are indicated to evaluate for concomitant and noncontiguous injuries. The Thoracolumbar Injury Classification and Severity (TLICS) score provides a framework for the evaluation of burst fractures as well as surgical decision-making. Its validity has been demonstrated recently in pediatric patients. Burst fractures must be differentiated from Chance fractures, which are caused by distraction rather than compression. Suspicion

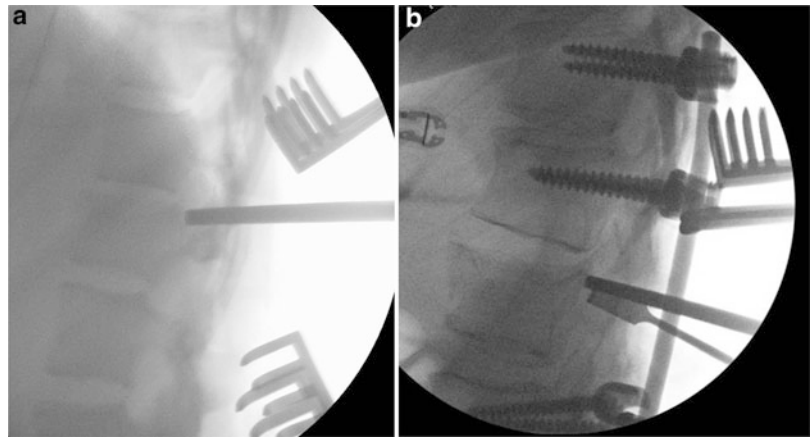
and evaluation for posterior ligamentous complex (PLC) injury is paramount in avoiding misdiagnosis of these injuries.

Our preference for surgical management of most unstable lumbar fractures below the conus medullaris is posterior instrumented fusion, with indirect reduction by ligamentotaxis or direct reduction by anterior tamping of the posterior column fragments. Fractures resulting in spinal cord compression, or those which cannot be reduced from a posterior approach, may benefit from anterior decompression and fusion with structural support. Finally, postoperative activity modification and bracing may be indicated until fusion is complete.

5 Basic Principles

1. Axial compression is the pathologic force that causes burst fractures as the elements of the intervertebral disc are driven through the vertebral endplate fracturing the body and disrupting the anterior and middle columns of the spine.
2. Radiographs should be evaluated for indicators of potential instability as well as posterior element injuries such as lamina and pedicle fractures and facet dislocations. Indicators of instability include local kyphosis ($>30^\circ$), coronal deformity, bony retropulsion ($>50\%$), and vertebral height loss ($>50\%$).
3. Advanced imaging with a CT scan can identify retropulsion of the fractured vertebral body (Fig. 1). An MRI scan can delineate the status of neurological elements and the integrity of the PLC.
4. Stable fractures have an intact PLC and do not have associated neurological injury or significant kyphosis or retropulsion. These injuries are typically treated with a thoracolumbosacral orthosis (TLSO) and activity modification for 8–12 weeks.
5. Patients with biomechanically unstable fractures are indicated for posterior spinal instrumentation and possible fusion. Our preference is to perform a short-segment fixation of the more lordotic middle and lower lumbar levels. A long-segment fixation (2 levels above and below) is deemed to be biomechanically superior and thus used for

Fig. 2 Intraoperative fluoroscopic images demonstrating the use of a bone tamp to reduce dorsally retropulsed fracture fragments (a). A nerve root retractor is used later in the case to aid in the visualization and reduction of more lateral fracture fragments (b)



injuries near or at the thoracolumbar junction. A fusion is performed for significant instability and/or posterior element fractures or dislocations.

6. Non-fusion treatment with removal of the instrumentation after fracture healing is preferred in some centers. An anterior decompression is typically performed for severe canal compromise, significant vertebral height loss, and kyphosis and/or thoracic injuries.
7. Postoperative activity modification and a TLSO brace are used for 12 weeks.
8. A gradual return to activity is supplemented with physical therapy.
9. Clinical follow-up is recommended for at least 1 year (Figs. 3 and 4). Pseudoarthrosis is rare in surgically treated patients, yet kyphotic deformity can progress in patients treated nonoperatively.
6. Pedicle screws are placed.
7. Appropriately curved rods are then inserted, followed by end caps. Rod connectors add rigidity to the construct.
8. Rod contouring into lordosis and distraction often provide indirect canal decompression, which is checked radiographically. Occasionally, myelographic dye can be used to look for any residual compression. If present, formal decompression is performed.
9. A laminectomy is performed. It is important to note that neural elements released via a traumatic durotomy can be herniated into a laminar defect. This is increasingly likely in the presence of posterior element fractures seen on preoperative scanning and should be anticipated.
10. Repair of any encountered traumatic durotomies is performed with 6-0 monofilament suture in a figure-of-eight interrupted fashion and augmented with a commercial fibrin sealant.
11. The decompression is then performed. In the lumbar spine, the dural tube can be mobilized to expose the retropulsed fragment lying ventrally. Free fragments can be removed with a pituitary rongeur. The fracture fragments are gently malletted ventrally with a straight or curved (for midline fragments) bone tamp using fluoroscopy to confirm the position of the tamp after impaction (Fig. 2). Indirect decompression of the nerve roots is performed at the level of the lateral recess and via foraminotomy as indicated.
12. A water-tight closure is carried out. A drain is placed and vancomycin powder is used in the subcutaneous layer.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

1. The patient is positioned prone with access to the fluoroscope.
2. Our preference is to utilize intraoperative neurophysiological monitoring to reduce the chance of iatrogenic neurological injury.
3. Our practice is to complete the spinal instrumentation prior to the decompression.
4. The skin incision and dissection is carried down to spine with the goal of exposing 1–2 levels above and 1–2 levels below the zone of injury (Fig. 3).
5. Posterior element fractures in the segments adjacent to the fracture may obviate screw placement at that level.

8 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

Fig. 3 Postoperative AP radiographs demonstrating correction of kyphosis and restoration of lumbar lordosis (a) and improved coronal alignment (b) with a long-segment fixation. Lateral radiograph 1-year post-op (c) with maintained alignment

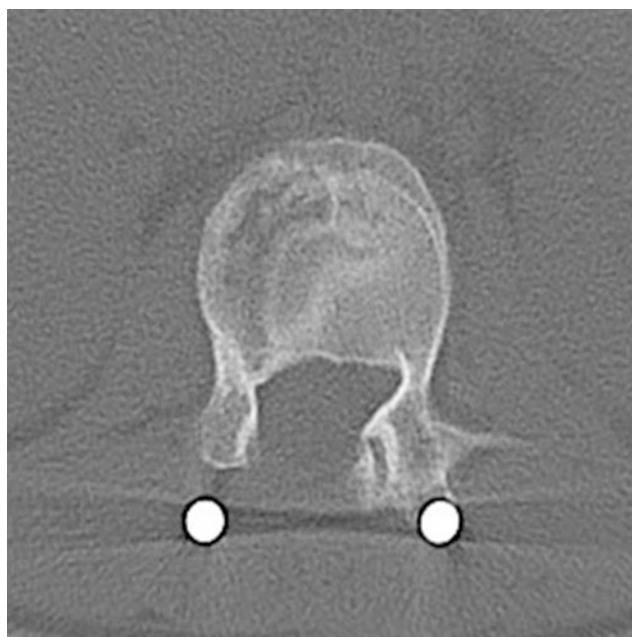
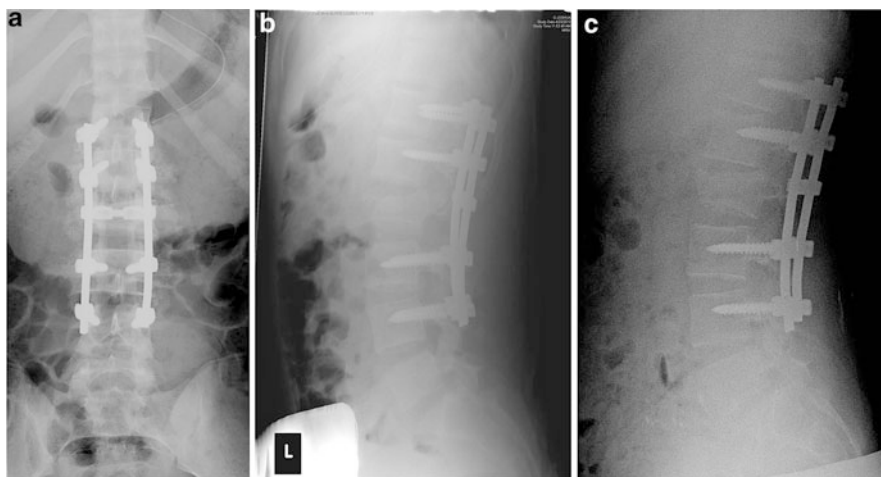


Fig. 4 Axial cut of burst fracture at 1-year post-op demonstrating remodeling of the spinal canal

9 Avoiding and Managing Problems

1. The pedicle entry sites along the thoracolumbar spine vary in the axial and sagittal planes. Understanding these anatomical differences will ensure safe screw insertion along the pedicle axis.
2. Rod breakage and/or persistent pain may indicate pseudoarthrosis. Open exploration and hardware exchange may be indicated. Additional bone grafting supplemented with BMP and bone graft substitutes can help achieve fusion.

10 Cross-References

- [Thoracic and Lumbar Compression Fractures](#)

References and Suggested Readings

- Andras LM, Skaggs KF, Badkoobehi H, Choi PD, Skaggs DL (2016) Chance fractures in the pediatric population are often misdiagnosed. *J Pediatr Orthop*. Post Date: December 23, 2016. <https://doi.org/10.1097/BPO.0000000000000925>

- Cox JB, Yang M, Jacob RP, Pincus DW (2013) Temporary percutaneous pedicle screw fixation for treatment of thoracolumbar injuries in young adults. *J Neurol Surg A Cent Eur Neurosurg* 74(1):7–11
- Cui S, Busel GA, Puryear AS (2016) Temporary percutaneous pedicle screw stabilization without fusion of adolescent thoracolumbar spine fractures. *J Pediatr Orthop* 36(7):701–708
- Daniels AH, Sobel AD, Eberson CP (2013) Pediatric thoracolumbar spine trauma. *J Am Acad Orthop Surg* 21(12):707–716
- Ilharreborde B, Hirsch C, Presedo A, Penneçot GF, Mazda K (2012) Circumferential fusion with anterior strut grafting and short-segment multipoint posterior fixation for burst fractures in skeletally immature patients: a preliminary report. *J Pediatr Orthop* 32(5):440–444
- Lazaro BC, Deniz FE, Brasiense LB, Reyes PM, Sawa AG, Theodore N, Sonntag VK, Crawford NR (2011) Biomechanics of thoracic short versus long fixation after 3-column injury. *J Neurosurg Spine* 14(2):226–234
- Louman-Gardiner K, Mulpuri K, Perdios A, Tredwell S, Crompton PA (2008) Pediatric lumbar chance fractures in British Columbia: chart review and analysis of the use of shoulder restraints in MVAs. *Accid Anal Prev* 40(4):1424–1429
- Santiago R, Guenther E, Carroll K, Junkins EP Jr (2006) The clinical presentation of pediatric thoracolumbar fractures. *J Trauma* 60(1):187–192
- Sellin JN, Steele WJ 3rd, Simpson L, Huff WX, Lane BC, Chern JJ, Fulkerson DH, Sayama CM, Jea A (2016) Multicenter retrospective evaluation of the validity of the thoracolumbar injury classification and severity score system in children. *J Neurosurg Pediatr* 18(2):164–170
- Vaccaro AR, Lehman RA Jr, Hurlbert RJ et al (2005) A new classification of thoracolumbar injuries: the importance of injury morphology, the integrity of the posterior ligamentous complex, and neurologic status. *Spine (Phila Pa 1976)* 30(20):2325–2333
- Vander Have KL, Caird MS, Gross S et al (2009) Burst fractures of the thoracic and lumbar spine in children and adolescents. *J Pediatr Orthop* 29:713–719

Thoracolumbar Flexion-Distract Injuries: Chance Fracture-Dislocations

Kevin M. Neal

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Abstract

Flexion-distract injuries of the thoracolumbar spine are relatively rare conditions in children. They are better known by the name “Chance” fractures. They have often been called “seatbelt” fractures, as the most common mechanism is a lap belt creating an anterior force during a motor vehicle accident, around which the posterior elements of the spine distract. The presence of a “seatbelt sign,” consisting of anterior abdominal bruising, is a helpful diagnostic finding. Because of the anterior force, these injuries are frequently associated with intraabdominal injuries, which may require more emergent surgery than the spine injury. The spinal column injury consists of an anteriorly directed flexion force, around which the rest of the spine distracts, with separation of the spinal elements, either through fractures in the vertebra or through tearing of the disk and ligamentous structures. Spinal cord injuries can occur, and, when

incomplete, have an excellent prognosis for eventual recovery. Chance fractures are inherently unstable. In very young children, nonoperative management with casting or bracing may be effective, but more commonly, operative stabilization is required, typically with limited posterior spinal fusion with instrumentation.

A 14-year-old boy presented to the emergency department following a motor vehicle accident. He was the backseat passenger in a car traveling at a high rate of speed that crashed into a concrete barrier. He was not using the shoulder harness portion of the seatbelt, but his lap belt was intact. He exhibited marked anterior abdominal bruising and severe pain in the abdomen and posterior trunk. An evaluation by the facility’s Trauma Surgeons determined that he had liver and splenic lacerations. He had intact motor strength and normal sensation in the legs. X-Rays, CT scan, and MRI scan of the lumbar spine showed a flexion-distract injury at the L3–4 level. The intraabdominal injuries were observed and the patient remained stable. Operative fixation of the injury was performed with a reduction of the kyphosis and posterior fusion with instrumentation from L3 to L4. The patient

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was fitted with a TLSO, and gradual weight-bearing was allowed immediately following the surgery. The patient achieved a solid fusion and full recovery from the injury.

1 Brief Clinical History

A 14-year-old boy was a back seat passenger in a motor vehicle accident where his car collided with a solid barrier. He was using only the lap belt portion of his restraint. He presented as a trauma patient to the emergency department, where further workup revealed anterior abdominal bruising from the lap belt, and intraabdominal injuries consisting of liver and splenic lacerations. Imaging also revealed focal kyphosis at L3-4, with separation of the L3-4 disk and L3 spinous process and posterior ligaments. He had a normal neurologic exam. Representative images from his X-rays, CT scan, and MRI scan are shown in Fig. 1.

2 Pretreatment Image

See Fig. 1a-c

3 Pretreatment Problem List

1. Liver and splenic lacerations
2. Flexion-distraction (Chance) injury at L3-4

4 Treatment Strategy

Because the force required to produce a flexion-distraction injury of the spine is typically directed anteriorly through the abdominal cavity, physicians should have a high index of

suspicion for intraabdominal trauma. Normal efforts consisting of trauma patient resuscitation and treatment are indicated. If emergent operative treatment of intraabdominal injury is required, it will likely have to take place before treatment of the spinal column injury. Significant intraabdominal injuries are found in up to two-thirds of cases with flexion-distraction injuries of the spine. Efforts to diagnose the spine injuries are important to maintain spine precautions while other injuries are addressed. Diagnosis is aided by noting the presence of anterior abdominal bruising, posterior thoracolumbar pain at the level of the injury, as well as possible crepitance or focal kyphosis. Imaging typically consists of plain x-ray, CT scan to delineate bony injury, and MRI scan to define injury to the soft elements.

In cases of purely bony injuries, nonoperative treatment, typically with TLSO bracing that attempts to extend the spine (produce lordosis), can be attempted. Bony injuries heal faster than ligamentous injuries. Similarly, younger children typically heal faster than adolescents and adults, and nonoperative treatment of flexion-distraction injuries can be considered in this age group. If nonoperative treatment is attempted, a lateral radiograph of the patient standing with the brace in place is required to confirm that it controls any instability of the injury, and prevents excessive kyphosis.

More commonly, these injuries have sufficient risk of instability such that surgical management is recommended. In patients with associated neurologic injuries, operative stabilization of the injuries is felt to give the best chance for compliance with rehabilitation and for neurologic recovery.

Though there are case reports of successful operative stabilization with single-level pedicle screw instrumentation or tension band wiring, typical instrumentation and fusion for flexion-distraction injuries will involve one to two levels above and below the injury. The decision for how many



Fig. 1 (a–c) Sagittal radiograph, CT scan, and T2-weighted MRI, demonstrating splaying of the L3 spinous process and posterior ligamentous disruption, indicative of a flexion-distraction injury

levels to include may be based on several factors including the amount of preoperative kyphosis, the quality of the patient's bone, the size of the patient, and the surgeon's experience.

Focal kyphosis from the injury is often reduced by standard positioning of the patient prone on a spine table. A posterior approach is preformed to the desired levels. Confirmation of levels can be accomplished by inserting a needle into a spinous process and obtaining a lateral radiograph or lateral fluoroscopy. The posterior musculature is dissected free from the posterior elements. Hematoma is cleaned from the fracture site. Pedicle screws are inserted using the surgeon's preferred technique. Rods are cut and contoured to the normal sagittal contours of the patient's spine. Additional kyphosis correction can be accomplished by applying compression to the posterior elements of the spine through the pedicle screws. The cortical bone of the posterior elements is disrupted using rongeurs, gouges, or a burr to allow bleeding that will stimulate a fusion mass. The addition bone graft is controversial, but may not be required in children and adolescents.

Postoperatively, patients are encouraged to weight bear as soon as possible, and to resume a normal diet as soon as possible. The presence of an intraabdominal injury may increase the risk of a postoperative ileus. The surgeon may prefer additional immobilization to aid fusion, and if so, a TLSO can be used for weight bearing, typically for a period of 6–12 weeks.



Fig. 2 Lateral radiograph showing a posterior spinal fusion with instrumentation with pedicle screws at L3 and L4, with reduction of the patient's preoperative kyphosis

5 Basic Principles

1. Spine precautions are maintained while the child is positioned prone on a spine table.
2. The level of injury can be localized using a sterile needle and lateral fluoroscopy.
3. A standard posterior approach to the posterior elements is performed.
4. Hematoma and any small loose bony fragments are removed from the fracture site.
5. Pedicle screws are placed bilaterally, typically one level above the injury and one level below the injury. The number of levels fused can be increased if there are concerns regarding the patient's weight, the patient's bone quality, or the need for greater kyphosis correction.
6. Rods are inserted into the pedicle screws on either side of the spine.
7. Compression is applied through the pedicle screws for stability, and to improve the kyphosis of the spine.
8. Early immobilization after surgery is encouraged.
9. Postoperative immobilization is optional, but can include a TLSO if there is a need for additional external stability.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

1. Preoperative kyphosis from the injury is often reduced simply by positioning the patient prone on the spine table.
2. In children and adolescents, bone grafting is optional. Sources of bone graft can include iliac crest autograft, allograft, and synthetic options. In young, healthy children and adolescents, bone grafting may not be required due to their excellent healing and fusion potential.
3. Pedicle screws can be placed in the same manner used for scoliosis surgery, which can include freehand/anatomic technique, adjunctive fluoroscopy, or 3D image guidance.

8 Avoiding and Managing Problems

1. Spine precautions should be maintained until definitive fixation is performed.

2. Ensure complete workup and treatment for intraabdominal pathology has been performed prior to considering spine surgery.
3. Soft tissue disruption from the fracture can expose the dura during the posterior approach to the spine. Care should be taken during dissection to avoid a dural tear.
4. Early postoperative immobilization helps prevent ileus, venous thrombosis, and pressure sores, especially in the setting of a spinal cord injury.

9 Cross-References

- [Management of Pediatric and Adolescent Thoracolumbar Burst Fractures](#)
- [Thoracic and Lumbar Compression Fractures](#)

References and Suggested Reading

- Chapman JR, Agel J, Jurkovich GJ, Bellabarba C (2008) Thoracolumbar flexion-distraction injuries: associated morbidity and neurological outcomes. *Spine (Phila Pa 1976)* 33(6):648–657
- Daniels AH, Sobel AD, Ebersson CP (2013) Pediatric thoracolumbar spine trauma. *J Am Acad Orthop Surg* 21(12):707–716
- Joseph SA Jr, Stephen M, Meinhard BP (2008) The successful short-term treatment of flexion-distraction injuries of the thoracic spine using posterior-only pedicle screw instrumentation. *J Spinal Disord Tech* 21(3):192–198
- Lopez AJ, Scheer JK, Smith ZA, Dahdaleh NS (2015) Management of flexion distraction injuries to the thoracolumbar spine. *J Clin Neurosci* 22(12):1853–1856
- Santiago R, Guenther E, Carroll K, Junkins EP Jr (2006) The clinical presentation of pediatric thoracolumbar fractures. *J Trauma* 60(1):187–192
- Verlaan JJ, Diekerhof CH, Buskens E, van der Tweel I, Verbout AJ, Dhert WJ, Oner FC (2004) Surgical treatment of traumatic fractures of the thoracic and lumbar spine: a systematic review of the literature on techniques, complications, and outcome. *Spine (Phila Pa 1976)* 29(7):803–814

Spinal Cord Injury Without Radiographic Abnormalities (SCIWORA)

John A. Heydemann, Brian E. Kaufman, and Suken A. Shah

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Abstract

Spinal cord injury without radiographic abnormalities (SCIWORA) is unique to children due to the elasticity of the spinal cord. Children present with complete or incomplete findings and as the name describes, there is no evidence of pathology on radiographs or computed tomography. Children with this injury require careful physical exam and scrutiny of the imaging before proceeding with further imaging studies, such as magnetic

resonance imaging (MRI), looking for soft tissue injury as well as rupture of the tectorial membrane. Intramedullary hemorrhage is a poor prognosis. Patients are typically immobilized until they display clinical evidence of healing and are stable on flexion and extension radiographs. Any late instability is treated with surgical intervention.

1 Brief Clinical History

This case is of a 3-year-old female who was involved in a motor vehicle accident. The patient was a restrained rear driver-side passenger seated in a booster seat with a shoulder harness during a t-bone collision. The patient was transported to an outside facility with a GCS of 12, which improved to 15. Computed tomography (CT) scans (Fig. 1a–e) did not reveal any bony injury, and the patient was transferred to our facility. The patient was treated with standard spinal precau-

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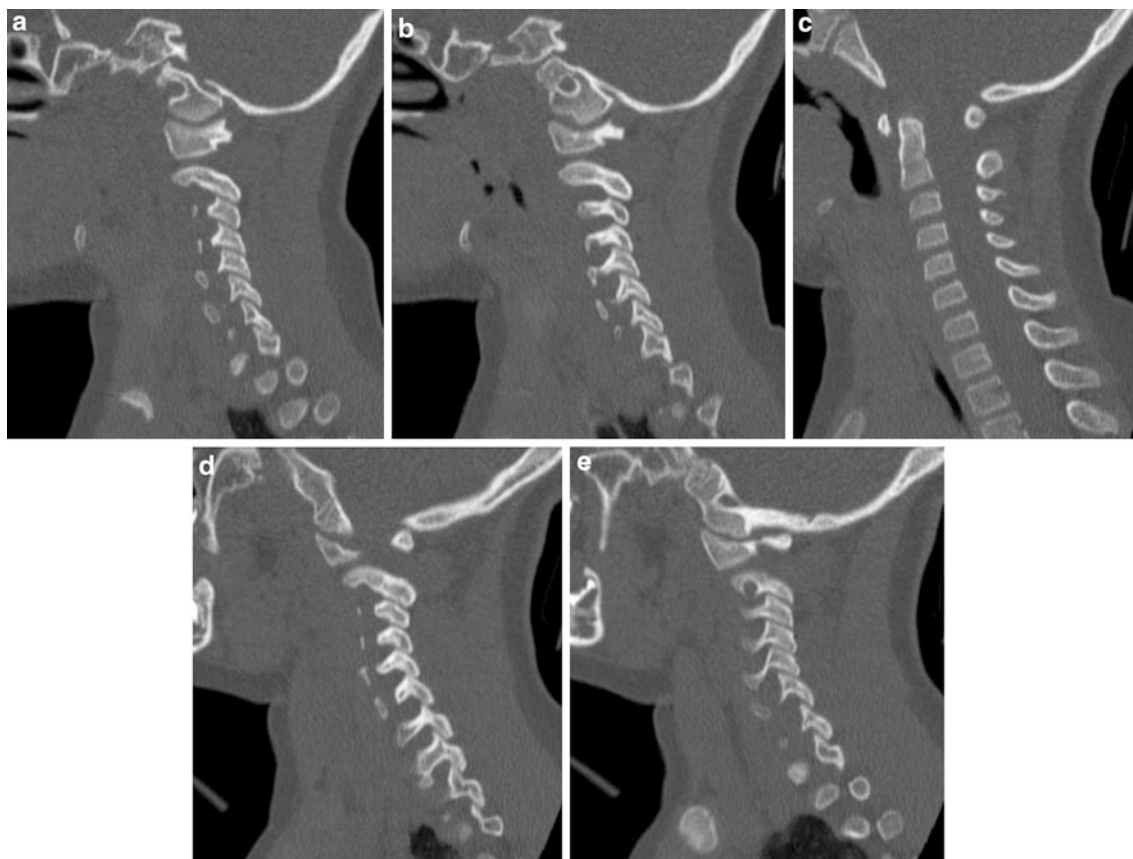


Fig. 1 (a–e) Sagittal CT of the cervical spine obtained upon initial arrival to the emergency room, demonstrating normal bony anatomy

tions, including the application of a cervical collar. Upon evaluation by the orthopedic service, the patient was not able to move her left upper extremity. She had midline and paraspinal cervical tenderness and weakness of the left upper and lower extremities.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

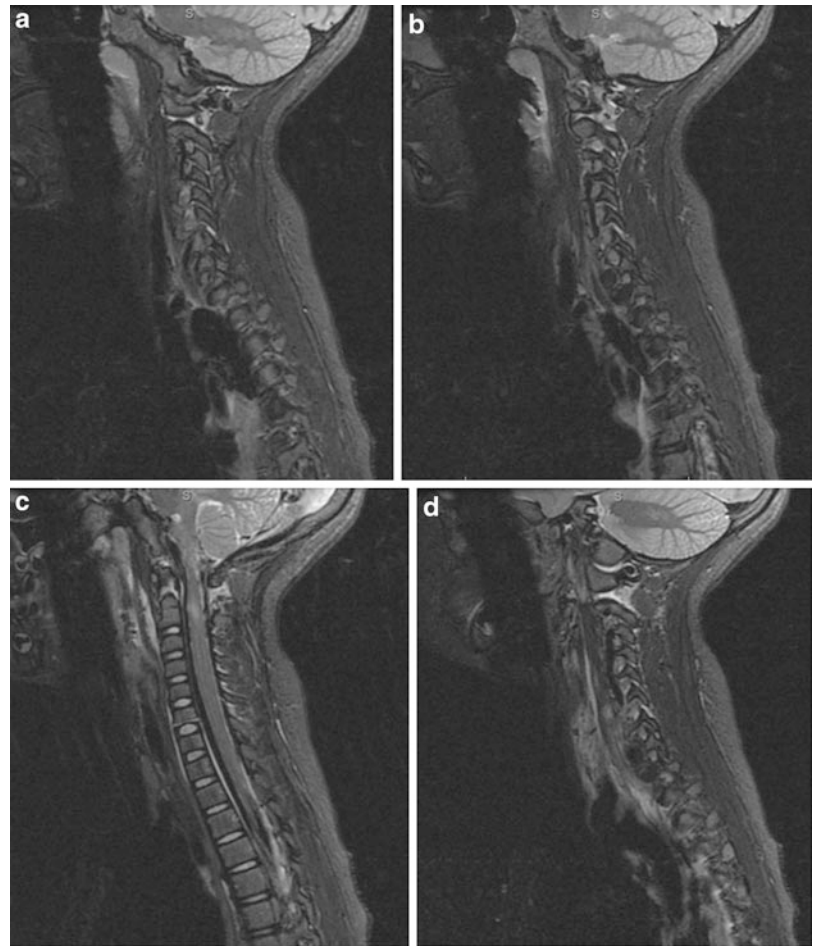
1. A patient with no motor or sensory function to the left upper or lower extremities
2. Possible spinal cord injury versus brachial plexus palsy (further imaging needed)
3. Additional distracting injuries: bilateral pulmonary contusions, right adrenal hematoma, liver lacerations, hemoperitoneum, left pubic ramus fracture, and a right sacral buckle fracture

4 Treatment Strategy

Upon arrival to the emergency room, the patient should be immobilized in a cervical collar if not done already, and strict spinal precautions are essential. Recall that due to the relative size of the child's head, patients should be placed on a modified backboard so that the patient is not placed into forced kyphosis of the neck (Herzenberg et al. 1989). The patient should then undergo a thorough history and physical and any neurologic deficits should be noted. Imaging of the cervical spine can be performed using standard radiographs, followed by CT and MRI scans. Careful scrutiny of the imaging may reveal a localized injury, but this case is typical of SCIWORA and did not reveal any injury on the plain radiographs or the CT scan. Following a diagnosis of SCIWORA, patients are immobilized appropriately in a traditional halo or pinless halo for 3 months with close follow-up in clinic (Loder 2014). A rigid cervical collar may be considered for children who are older and understand the necessity of the device and not remove it.

For our patient, a MRI study was ordered for further evaluation of her spine (Fig. 2a–d). The MRI revealed occipitoaxial and atlantoaxial capsular ligamentous edema,

Fig. 2 (a–d) Sagittal MRI of the cervical spine



spinal cord contusion at C2, an unstable transverse fracture along the inferior endplate of C6 with associated ligamentous disruption, and a thin anterior epidural hematoma without associated cord compression. Other orthopedic injuries included a left pubic ramus fracture and a right sacral buckle fracture. Options were discussed with the patient and her family. The patient was immobilized in a pinless halo device for 6 weeks (Fig. 4a, b). She was followed regularly with lateral cervical spine radiographs (Figs. 3 and 5). At 6 weeks, she was transitioned to a rigid cervical orthosis (Fig. 6).

incomplete findings may be present. SCIWORA is more common in children less than 8 years old. Patients must be immobilized after the initial event (Warner and Hedequist 2010). MRI is the most useful study to evaluate the spinal cord for positive findings in children with neurologic involvement (Loder 2014). The best treatment for SCIWORA remains controversial. Most studies recommend bracing for 3 months, followed by flexion and extension radiographs (Pang and Pollack 1989). Any late instability should be addressed with surgical stabilization (Loder 2014).

5 Basic Principles

The definition of SCIWORA is a spinal cord injury that does not have any visible fracture or dislocation on plain radiographs or CT scans. The incidence is reported as ranging from 18% to 38% of all pediatric spinal cord injuries (Jones et al. 2011). This condition is unique to children and believed to be related to a more elastic spinal cord. Four major causes related to this injury include hyperextension, flexion, distraction, and spinal cord ischemia (Loder 2014). Complete or

6 Images During Treatment

See Figs. 2 and 3.

7 Technical Pearls

It is important to ensure that the provider performs a thorough, well-documented physical exam, which is repeated throughout the course of treatment. This is followed by

appropriate imaging studies. Be aware that some patients have a rupture of the tectorial membrane, which can be a subtle finding. Intramedullary hemorrhage is a predictor of a poor prognosis.

8 Outcome Clinical Photos and Radiographs

See Figs. 4, 5, and 6.

9 Avoiding and Managing Problems

Problems can be avoided by ensuring that patients are properly immobilized as soon as possible following cervical trauma. A thorough history and physical exam are critical to isolate any neurologic deficits. A careful evaluation of imaging studies is essential to ensure that a true cervical spine injury is not missed. Close follow-up of patients, with continued evaluation in the clinic, can identify any spinal instability, indicating a need for surgical intervention.

► Editors' Tips and Pearls

Young children who present to the emergency department intubated with a suspected traumatic brain injury should be carefully assessed to insure that they do not have a high spinal cord injury/SCIWORA. SCIWORA can present as a diagnostic dilemma if there is a very high complete spinal cord injury in a young child, as central neurological control of respiration can be blocked necessitating endotracheal intubation. The patient then will be "locked in" with paralysis of all extremities and inability to communicate verbally because of inability to generate voluntary respiration and presence of endotracheal tube. These children may initially be diagnosed with a



Fig. 3 Cross table lateral in the pinless halo after application

Fig. 4 (a, b) Clinical photographs of our patient wearing the pinless halo

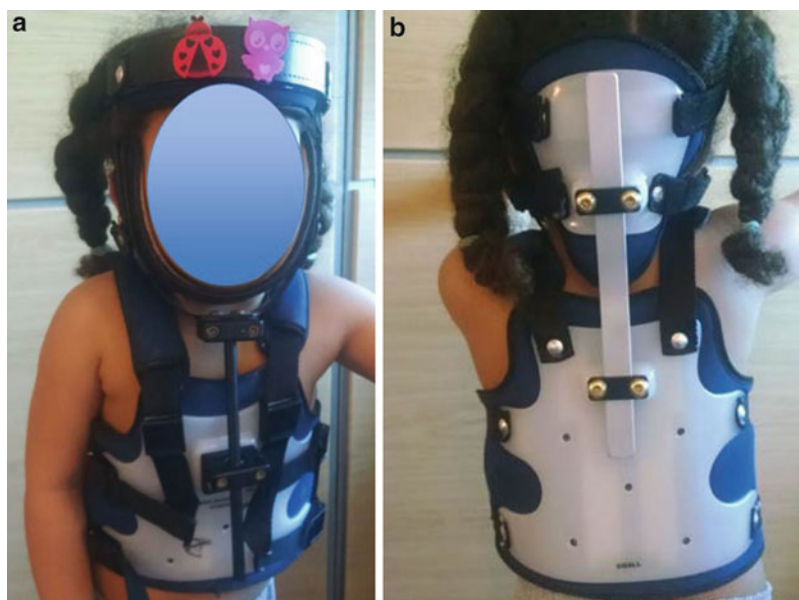




Fig. 5 Cross table lateral cervical spine radiograph at 2 weeks into treatment

severe traumatic brain injury, however they will have spontaneous eye opening, tracking with their eyes, and can follow commands when instructed to blink, or to look left or right.

10 Cross-References

► Unilateral Cervical Facet Fracture-Dislocation



Fig. 6 Cross table lateral cervical spine radiograph at 6 weeks post injury. The patient is now in a rigid cervical collar

References

- Herzenberg JE, Hensinger RN, Dedrick DK et al (1989) Emergency transport and positioning of young children who have an injury of the cervical spine. The standard backboard may be hazardous. *J Bone Joint Surg* 71(1):15–22
- Jones T, Anderson P, Noonan K (2011) Pediatric cervical spine trauma. *J Am Acad Orthop Surg* 19:600–611
- Loder R (2014) The cervical spine. In: Weinstein SL, Flynn JM (eds) *Lovell and Winter's Pediatric orthopedics*, 7th edn. Lippincott Williams & Wilkins, Philadelphia, pp 821–893
- Pang D, Pollack IF (1989) Spinal cord injury without radiographic abnormality in children – the SCIWORA syndrome. *J Trauma* 29(5):654–664
- Warner W, Hedequist D (2010) Cervical spine injuries in children. In: Beaty JH, Kasser JR (eds) *Rockwood and Wilkin's fractures in children*, 7th edn. Lippincott Williams & Wilkins, Philadelphia, pp 685–722

Part IV

Pelvis and Hip

Ischial Tuberosity Avulsion Fracture

Kevin E. Klingele and Jeff Otte

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Abstract

Ischial tuberosity avulsion fractures are uncommon injuries typically seen in adolescent athletes during activities of forced hip flexion with an extended knee position. The injury is often accompanied by the sudden onset of pain and a “popping” sensation in the proximal thigh or buttock region. Initial workup should include a thorough history and clinical exam with pelvic radiographs in the suspected patient. Conservative treatment with rest, restricted activity, and rehabilitation is typically reserved for fractures displaced less than 15 mm. Surgical management is recommended for fragments with displacement greater than 15 mm, those patients who fail conservative treatment, symptomatic nonunions, or for patients with sciatic nerve symptoms. A subgluteal approach is a safe approach that allows adequate reduction and fixation of the

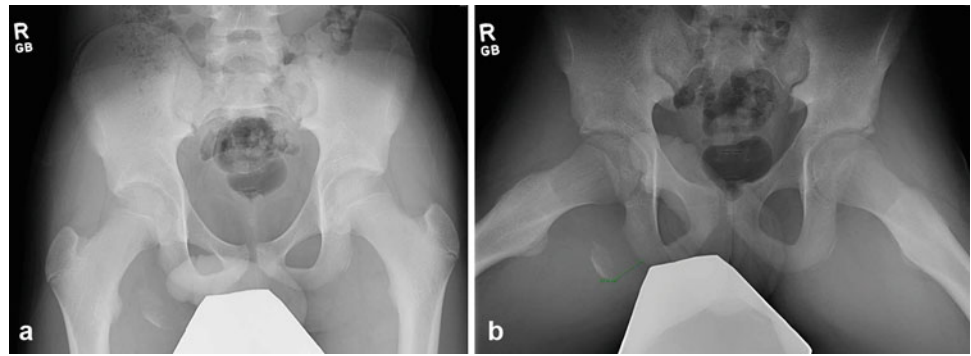
fragment. Advantages of this approach include the ability to obtain direct access of the fragment without exposing the sciatic nerve but, at the same time, providing the flexibility of extending the incision to expose the sciatic nerve when necessary. This approach also provides indirect reduction of the displaced ischial fragment with the patient positioned prone and the hip and knee slightly flexed. Symptomatic nonunion can be a complication in patients treated conservatively with severe, initial displacement >15 mm.

1 Brief Clinical History

A healthy skeletally immature, 14-year-old male track athlete presents with history of a sudden onset of pain and “popping” sensation in his proximal thigh, causing him to fall to the ground. Plain radiographs of the pelvis demonstrate a significantly displaced ischial tuberosity avulsion fracture (Fig. 1).

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Fig. 1 Plain radiographs at the time of the injury. **a** AP pelvis demonstrating a significantly displaced right ischial tuberosity avulsion fracture. **b** Frog leg pelvis showing 2.2 cm of displacement



On physical exam, he was a healthy-appearing adolescent male with tenderness and a palpable gap about his proximal hamstring origin. He was weak with active knee flexion and had an antalgic gait. No neurologic deficit was present.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

- Gait disturbance
- Function-limiting pain
- Acute significantly displaced ischial tuberosity avulsion fracture

4 Treatment Strategy

An initial trial of nonsurgical management with rest, restricted activity, and rehabilitation is recommended in cases with initial displacement of less than 15 mm (Kujala and Orava 1993; Kujala et al. 1997; Kocis et al. 2003). The time to return to full sport activity is approximately 6–12 weeks. Surgical treatment should be considered when the avulsed ischial tuberosity is displaced more than 15 mm, in patients that have failed conservative treatment irrespective of the amount of displacement, or in cases where the sciatic nerve is symptomatic (Kujala and Orava 1993; Vandervliet 2007; Sulko et al. 2011). In the acute setting, the authors recommend open reduction and internal fixation via the subgluteal approach. Following general anesthesia, the patient is placed in the prone position with his hip and knee in a slightly flexed position. A 5–8 cm, transverse incision is made within the gluteal crease. The

inferior edge of the gluteus maximus was defined and elevated with blunt dissection. The plane between the gluteus maximus and the hamstring muscles is developed and the gluteus maximus retracted proximally. The avulsed fragment is present at the proximal end of the hamstring conjoint tendon and is reduced and provisionally held in place with one to two smooth K-wires. Prior, limited subperiosteal exposure of the ischial origin will aid in verification of reduction. The use of a large Hohmann retractor may also aid reduction by placing the Hohmann spike at the conjoint tendon-bone interface and levering the fragment proximally. Once reduction is verified and held, screw fixation is performed. Fragment size dictates appropriate fixation, but typically the authors utilize 4.5 mm non-cannulated screws. Postoperatively, the patient is made touch-down weight bearing in a hip abduction brace to prevent hip flexion for a total of 4 weeks.

5 Basic Principles

The ischial apophysis serves as the origin of the proximal hamstring tendon complex, made up of the long head of the biceps femoris, the semitendinosus, and the semimembranosus muscle. This apophysis generally appears between 13 and 15 years of age and fuses to the pelvis at age 16 or as late as 25 years of age (Flecker 1942). As the physis is generally weaker than the tendinous insertion, the apophyseal center is mechanically susceptible to avulsion injury through its physis. Adolescent athletes who have yet to fuse the ischial apophysis are especially at risk for these injuries during activities requiring rapid acceleration and deceleration such as in dancing, track and field, football, and gymnastics (Muscato et al. 2001). If displaced greater than 15–20 mm, such injuries are equivalent to complete, proximal hamstring rupture, and surgical intervention should be discussed.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

The authors recommend an open approach to the displaced ischial fragment in order to obtain adequate visualization for reduction and fixation. We have found that the subgluteal approach allows safe, easy access to the fragment with the ability to avoid the sciatic and posterior femoral cutaneous nerves located lateral to the ischial tuberosity. Furthermore, this approach requires the patient to be positioned prone with the hip and knee slightly flexed, providing indirect reduction of the hamstring origin and making open reduction of the fragment easier. If there is clinical evidence of sciatic nerve injury or in cases of revision surgery for nonunion, the subgluteal approach can be modified to allow access to the pathology. Using a similar incision in the gluteal fold, proximal retraction of the gluteus maximus first allows exposure of the fragment, but with further dissection lateral, the sciatic nerve can be exposed (Miller et al. 1987). Alternatively, a longitudinal incision running from the gluteal crease down to the posterolateral thigh allows sciatic neurolysis and a z-lengthening of the hamstring tendons if needed to visualize, mobilize, and reduce the fragment.



Fig. 2 Intraoperative fluoroscopic image of the patient from Fig. 1 demonstrating three fully threaded 4.5 mm screws across an anatomically reduced ischial tuberosity avulsion fracture

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

If the symptoms of an ischial tuberosity avulsion fracture are misinterpreted, a significant delay in diagnosis can result, which may ultimately necessitate more extensive surgery (Gidwani and Bircher 2007). Therefore, a correct and timely diagnosis is essential to facilitate optimal treatment. In addition to a thorough history and clinical examination, radiographs of the pelvis should be performed in patients with adequate trauma and clinical findings. In cases of unsuspected radiographs, ultrasonography or magnetic resonance imaging (MRI) may be helpful to reveal soft tissue injury (Gidwani et al. 2004). Potential complications of conservative treatment include nonunion of the avulsed fragment. The resultant pseudoarthrosis may be associated with chronic pain, the inability to sit for a longer period of time, and a significantly decreased ability to perform sports (Kujala et al. 1997). In such cases, the authors recommend nonunion repair, with a low threshold to extend the approach in order to obtain adequate visualization of the chronic injury and/or the sciatic nerve as described above. Sciatic nerve symptoms may arise in patients treated conservatively or as a



Fig. 3 AP pelvis radiograph of the patient from Fig. 1 demonstrating well-maintained reduction with stable screw fixation with minimal pain on exam

complication after surgical treatment. If the symptoms do not resolve in a reasonable time frame, the authors recommend sciatic neurolysis.

10 Cross-References

- [Hip Dislocation](#)
- [Hip Dislocation with Acetabular Fracture](#)
- [Hip Dislocation with Proximal Femoral Physeal Fracture](#)

References and Suggested Readings

- Bahk WJ, Brien EW, Luck JV Jr, Mirra JM (2000) Avulsion of the ischial tuberosity simulating neoplasm—a report of 2 cases. *Acta Orthop Scand* 2:211–214
- Flecker H (1942) Time of appearance and fusion of ossification centers as observed by roentgenographic methods. *Am J Roentgenol* 47:97–159
- Gidwani S, Bircher MD (2007) Avulsion injuries of the hamstring origin—a series of 12 patients and management algorithm. *Ann R Coll Surg Engl* 4:394–399
- Gidwani S, Jagiello J, Bircher M (2004) Avulsion fracture of the ischial tuberosity in adolescents: an easily missed diagnosis. *BMJ* 329:99–100
- Kocis J, Visna P, Vesely R (2003) Traumatic avulsion of the tuberosity of the ischium. *Acta Chir Orthop Traumatol Cechoslov* 70:311–313
- Kujala UM, Orava S (1993) Ischial apophysis injuries in athletes. *Sports Med* 16:290–294
- Kujala UM, Orava S, Karpakka J et al (1997) Ischial tuberosity apophysitis and avulsion among athletes. *Int J Sports Med* 18:149–155
- Milch H (1935) Partial resection of the ischium. *J Bone Joint Surg* 17:166
- Miller A, Stedman GH, Beisaw NE et al (1987) Sciatica caused by an avulsion fracture of the ischial tuberosity. *J Bone Joint Surg Am* 69-A:143–145
- Muscato M, Lim-Dunham J, Demos TC, Lomasney LM (2001) Avulsion fracture of the apophysis of the ischial tuberosity. *Orthopedics* 12(1127):1198–1200
- Pruner RA, Johnston CE 2nd (1990) Avulsion fracture of the ischial tuberosity. *Orthopedics* 3:357–358
- Rossi F, Dragoni S (2001) Acute avulsion fractures of the pelvis in adolescent competitive athletes: prevalence, location and sports distribution of 203 cases collected. *Skelet Radiol* 3:127–131
- Spinner RJ, Atkinson JL, Wenger DE et al (1998) Tardy sciatic nerve palsy following apophyseal avulsion fracture of the ischial tuberosity: case report. *J Neurosurg* 89:819–821
- Sulko J, Olipra W, Oberc A (2011) Ischial tuberosity fractures in children. *Chir Narzadow Ruchu Ortop Pol* 76:134–137
- Vandervliet EJ, Vanhoenacker FM, Snoeckx A et al (2007) Sports-related acute and chronic avulsion injuries in children and adolescents with special emphasis on tennis. *Br J Sports Med* 41:827–831
- Wootton JR, Cross MJ, Holt KW (1990) Avulsion of the ischial apophysis. The case for open reduction and internal fixation. *J Bone Joint Surg Br* 4:625–627

Pubic Symphysis Disruption

Jason W. Stoneback

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Abstract

A 7-year-old male hit by a car while on a bicycle presented with multiple injuries including closed head injury, bilateral pulmonary contusions, pelvic ring injury, and right femur shaft fracture. The child was hemodynamically unstable with widening of the symphysis pubis and left sacroiliac joint disruption. The pelvis fracture protocol was initiated. Hemodynamic stability was obtained after sheeting of the pelvis and volume resuscitation including packed red blood cells. The patient underwent damage control temporary stabilization with external fixation of the pelvis and femur shaft fractures due to severe closed head injury and bilateral pulmonary contusions. Once the patient stabilized hemodynamically, definitive fixation of the pelvis was discussed including use of nonabsorbable suture fixation for the symphysis disruption versus plate

and screw construct. Open reduction and internal fixation (ORIF) of the symphysis with plate and screws was selected given the left hemipelvic instability with left sacroiliac (SI) screw fixation performed to address the left SI joint disruption. He remained nonweight-bearing on his left lower extremity for 10 weeks postoperatively. At 3 month follow up, the pubic symphysis disruption and pelvic ring injury had healed with good pelvic symmetry and no pain with activities. Given the patient's age and level of skeletal maturity, elective hardware removal will occur 1 year postoperatively.

1 Brief Clinical History

A 7-year-old male was pedaling on his bicycle when he was struck by an oncoming car. The child presented with multiple injuries including closed head injury, bilateral pulmonary contusions, pubic symphysis, and left SI joint disruption with right femur shaft fracture. The patient was hemodynamically unstable and required damage control stabilization of

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the pelvic ring and femur shaft fracture with temporary external fixation. Once the patient was medically stabilized, definitive pubic symphysis fixation was considered. Options for definitive fixation of the pubic symphysis disruption included maintaining pelvic external fixator as definitive anterior fixation, ORIF with nonabsorbable suture through drill holes in the symphysis or ORIF with plate screw construct. Given the significant left hemipelvis instability, ORIF with plates and screws was selected.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Pubic symphysis disruption
2. Unstable left SI joint
3. Skeletally immaturity
4. Possible urethral injury
5. Polytrauma patient with closed head injury

4 Treatment Strategy

Hemodynamic stability was achieved following damage control temporary external fixation of the pelvic ring injury. Due to the wide displacement of the pubic symphysis, retrograde urethrogram was performed ruling out urethral injury prior to any possible open reduction and internal fixation of the symphysis. Definitive stabilization of the pubic symphysis was considered with multiple techniques including continued management in the external fixator. External fixation was not selected as it would not be stable enough to maintain anatomic reduction, risk of pin tract infection, and poor patient satisfaction with prolonged external fixation. Open reduction and internal fixation techniques include use of nonabsorbable suture through osseous drill holes in the symphysis. Advantages of this technique include negating the need for hardware removal due to skeletal immaturity. Disadvantages of suture technique include less rigid fixation when compared with plate and screw constructs. The unstable left SI joint, polytrauma status with contralateral femur shaft fracture, and closed head injury were considered and the most rigid fixation method was selected. A four-hole 3.5-mm reconstruction plate with two 3.5-mm cortical screws placed on either side of the symphysis was utilized to stabilize the symphysis disruption. The patient's closed head injury required

monitoring of intracranial pressure (ICP) and elevated head of bed to keep ICPs within acceptable limits. Definitive pelvic fixation was delayed until ICPs remained stable with the patient lying flat for prolonged periods of time.

5 Basic Principles

1. Patients with pelvis fractures must be fully evaluated by the trauma team to rule out associated injuries.
2. Institutions that take care of critically injured patients with pelvic fractures should have an institutional protocol to deal with hemodynamically unstable pelvis fractures.
3. Preoperative radiographic evaluation includes AP, inlet and outlet pelvis x-rays, and CT pelvis. Close scrutiny of the posterior ring must occur to rule out injury requiring posterior ring stabilization.
4. A thorough physical examination should be performed to diagnose possible open fracture or genitourinary injury. Placement of Foley catheter and retrograde urethrogram should be performed with any symphysis disruption.
5. Hemodynamic stability should be achieved prior to definitive pelvic stabilization. Closed head injury requiring ICP monitoring should be assessed for stability and patient ability to remain flat for prolonged operating room time.
6. Definitive internal fixation methods include nonabsorbable suture through osseous drill holes in the symphysis. Advantages include lack of need for hardware removal but provides less rigid fixation than plate and screw constructs.
7. ORIF of the symphysis with plate and screws provides anatomic and rigid fixation. Depending on level of skeletal maturity, hardware may need to be removed after injury healing.
8. Skeletally immature patients remain nonweight-bearing on the injured hemipelvis side for 10 weeks postoperatively. Weight-bearing is then advanced as tolerated.

6 Images During Treatment

See Figs. 2 and 3.

7 Technical Pearls

1. Foley catheter should be placed preoperatively to decompress bladder during surgical approach.
2. If an external fixator has been placed, it can be prepped into the sterile field and used to assist with or maintain symphysis reduction during internal fixation.

Fig. 1 (a) Injury AP pelvis x-ray revealing widened symphysis and bilateral SI joints. (b) Injury CT of the pelvis prior to sheet placement with disruption and widening of the pubic symphysis

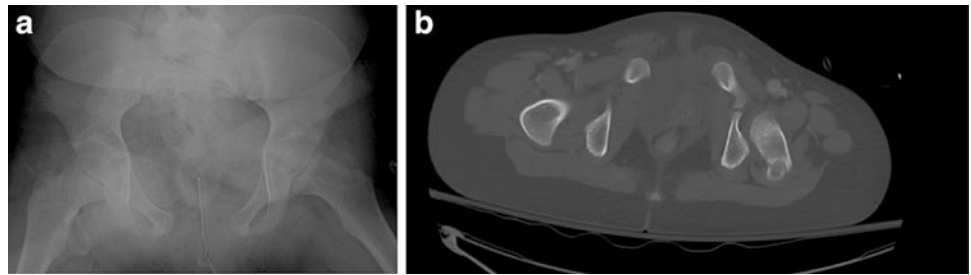


Fig. 2 (a) AP pelvis x-ray post external fixation with reduced symphysis. (b) Inlet pelvis x-ray post external fixation with reduced symphysis and widened bilateral SI joints

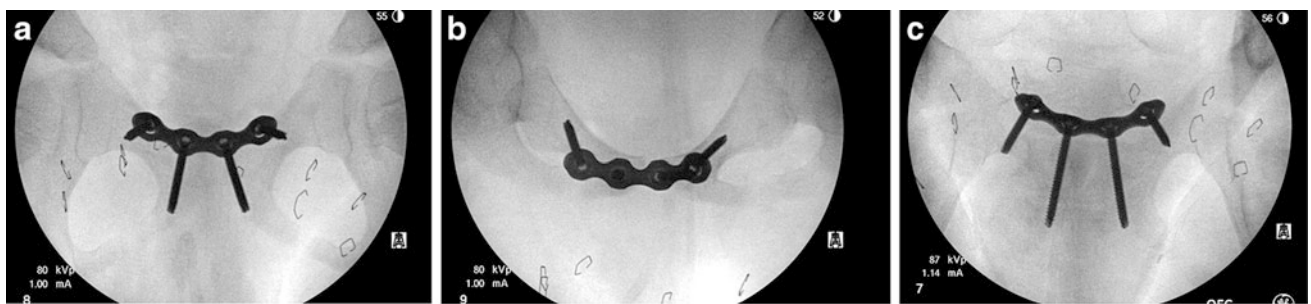
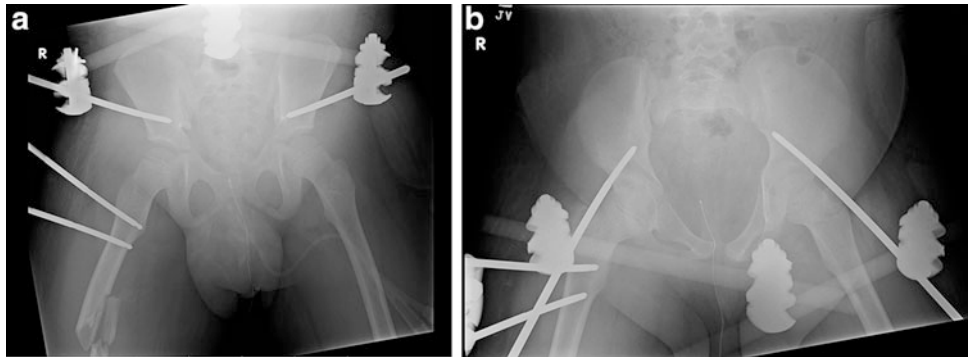


Fig. 3 (a–c) Intraoperative AP (a) inlet (b) and outlet (c) fluoroscopic images with reconstruction plate fixation of symphysis. Symphysis is anatomically reduced

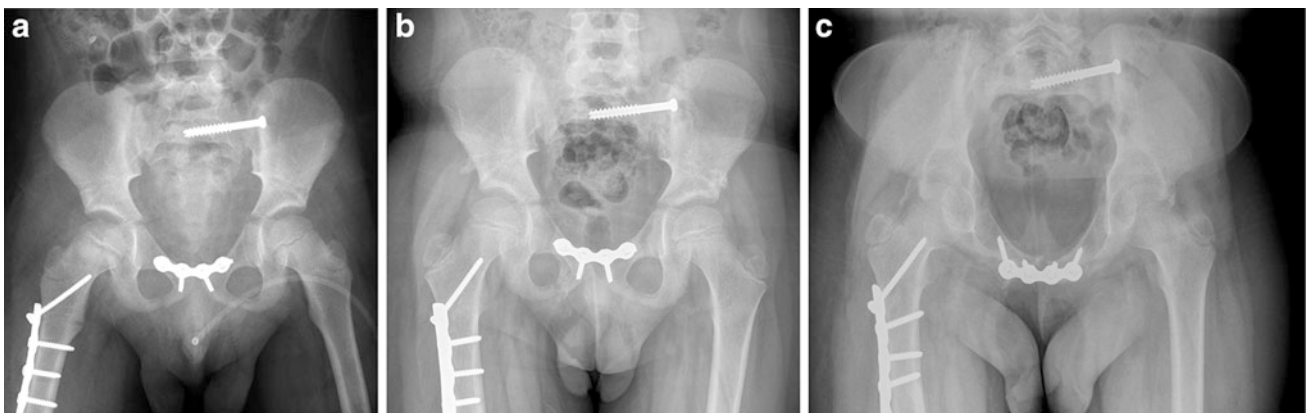


Fig. 4 (a–c) Three month postoperative AP (a) outlet (b) and inlet (c) fluoroscopic images with reconstruction plate fixation of symphysis, *left* SI screw and *right* femur fixation

3. Radiolucent retractors can facilitate intraoperative imaging.
4. Intraoperative reduction is best achieved with a Weber clamp in the obturator foramen and once temporary reduction is achieved, can be stabilized with a trans-symphyseal k-wire during plate or suture fixation.
4. Assure tight fascial closure to prevent postoperative hernia.
5. Consider general surgery or urology co-surgeon to assist with surgical approach if history of prior abdominal surgery.

8 Outcome Clinical Photos and Radiographs

See Fig. 4.

9 Avoiding and Managing Problems

1. Assure careful preoperative examination to rule out open fracture.
2. Confirm adequate retrograde urethrogram performed prior to internal fixation of the symphysis.
3. Monitor intraoperative Foley and urine for signs of iatrogenic bladder injury.

10 Cross-References

- [Pubic Rami Fracture with Disruption of the Sacroiliac Joint \(Malgaigne Fracture\)](#)

References and Suggested Reading

- Amorosa LF, Kloen P, Helfet DL (2014) High-energy pediatric pelvic and acetabular fractures. *Orthop Clin North Am* 45(4):483–500
- Hagedorn JC, Voelzke BB (2015) Pelvic-fracture urethral injury in children. *Arab J Uro* 13:37–42
- Langford JR, Burgess AR, Liporace FA et al (2013a) Pelvic fractures: part 1. Evaluation, classification and resuscitation. *J Am Acad Orthop Surg* 21(8):448–457
- Langford JR, Burgess AR, Liporace FA et al (2013b) Pelvic fractures: part 2. Contemporary indications and techniques for definitive surgical management. *J Am Acad Orthop Surg* 21(8):458–468

Pubic Rami Fracture with Disruption of the Sacroiliac Joint (Malgaigne Fracture)

Omar H. Atassi and Jaclyn F. Hill

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Abstract

First described by French Surgeon Joseph-Francois Malgaigne, vertical shear fractures of the pelvis are rare injuries often seen from high-energy trauma, typically falls from a height or a planted foot in a motor vehicle crash. They are characterized by an injury to the sacroiliac joint as well as ipsilateral vertically oriented pelvic rami fractures. There is complete disruption of the strong stabilizing ligaments of the posterior pelvic ring, including the sacrotuberous, sacrospinous, and anterior/posterior sacroiliac ligaments, resulting in complete sacroiliac joint instability and vertical displacement of the hemi-pelvis. Examination of the

genitourinary system and neurovascular status is critical. Aggressive resuscitation and stabilization should occur during the hospitalization, and multiple services, including general surgery, urology, and orthopedic surgery, may be necessary for optimal management. Classification is described using the Young and Burgess Classification. Unlike other pediatric pelvic ring injuries, those affecting the sacroiliac joint, particularly with vertical instability, often require surgical stabilization. Successful and maintained reduction of the sacroiliac joint is essential for good long-term outcomes. Definitive surgical management should occur within the first week, once the patient has been adequately resuscitated, preoperative imaging and planning have been completed, and all personnel and equipment is available. Blood products should be available during the procedure. There are various percutaneous and open fixation methods available. Obtaining excellent fluoroscopic images is necessary. Understanding the available osseous corridors for screw placement is critical to avoiding iatrogenic nerve root injury. Poor outcomes are

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correlated to malreduction of the sacroiliac joint, leg length discrepancy, as well as associated neurologic or genitourinary injuries.

1 Brief Clinical History

The patient is a 17-year-old girl who presented after a motor vehicle crash, front seat passenger, with pelvic pain. Patient is alert and oriented and hemodynamically stable on presentation. Patient's right leg is shorter than the left. She reports pain with log roll on the right side. There is pain and instability to rotation of the right hemi-pelvis. There is no skin changes noted along the

pelvis. Rectal exam demonstrates good tone and intact sensation without blood. Vaginal examination is negative for blood. Bilateral legs are neurovascularly intact. Computed tomography (CT) abdomen demonstrates a grade IV liver laceration.

2 Preoperative Clinical Photos and Radiographs

See Figs 1, 2, 3, and 4.

3 Preoperative Problem List

1. Right vertical shear pelvic ring injury (Malgaigne fracture)

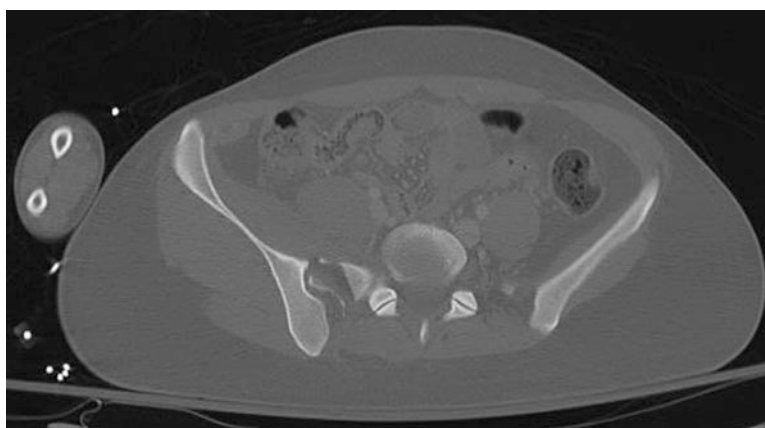
4 Treatment Strategy

A primary and secondary survey followed by a delayed tertiary survey is necessary to identify all injuries. The patient requires aggressive resuscitation upon presentation and throughout hospitalization, particularly during the second inflammatory hit. Open fractures require immediate intravenous antibiotics and bedside irrigation followed by urgent surgical irrigation and debridement. Neurovascular injuries must be identified and managed appropriately. The lumbosacral plexus and iliac vessels are tethered by the ligamentous structures and thus risk injury with vertical displacement of the hemi-pelvis. Thus, there is risk for hemorrhagic bleeding which may result in large transfusion requirements. Long bone fractures of the femur and tibia should be managed urgently to aid in the resuscitative process and prevent pulmonary complications. The hemi-pelvis may benefit from skeletal traction to reduce the hemi-pelvis as the patient awaits surgery. Further imaging, including inlet/outlet and CT reconstruction, should be



Fig. 1 AP pelvis obtained in the trauma room demonstrates a vertically oriented right superior and inferior pubic rami fractures with complete disruption of the right sacroiliac joint and resulting vertical displacement of the right hemi-pelvis

Fig. 2 Axial CT cut demonstrates a component of the fracture exiting through the sacrum lateral to the foramen



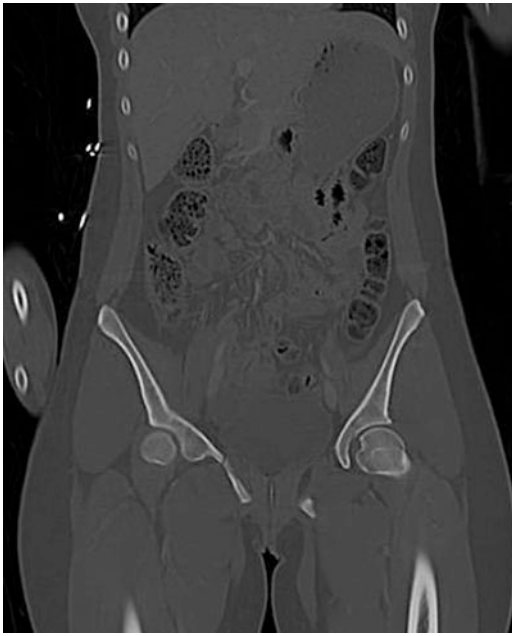


Fig. 3 Coronal CT cut demonstrates a vertically oriented superior ramus fracture

obtained for surgical planning. CT scan is used to understand the available osseous corridors for future screw placement. The patient is ready for surgery once the patient is adequately resuscitated and the proper equipment and personnel are available.

5 Basic Principles

The patient should be positioned supine, and an attempt should be made to obtain a closed reduction. The primary reduction should be in-line traction of the affected hemipelvis. If reduction cannot be obtained via closed methods, the patient may require an open reduction of the sacroiliac joint via a posterior (prone) or anterior (supine) approach. Reduction can then be obtained via a combination of closed (i.e., traction), percutaneous (i.e., Schanz pins), or temporary external fixator placement. Reduction is verified using orthogonal fluoroscopic images. AP demonstrates flexion/extension and external/internal rotation alignment. Inlet demonstrates anterior/posterior and external/internal rotation alignment. Outlet demonstrates superior/inferior and external/internal rotation alignment. Attention is then turned to fixation. There are several factors, including surgeon preference and injury pattern that may dictate the order between anterior and posterior fixation. In the case of complete sacroiliac dissociation, typically, the surgeon first approaches instrumentation of the posterior ring. A lateral is obtained in order to establish the appropriate starting point with the sacral body and iliac cortical



Fig. 4 Coronal CT cut of the posterior ring demonstrates a fracture dislocation of the right sacroiliac joint with resulting vertical displacement of the right hemipelvis. Also visible is fracture of the right L5 transverse process, suggesting injury to the lumbo-sacral ligaments which contribute to vertical stability of the hemipelvis

densities as the key landmarks (Roult et al. 1997). Then, using inlet and outlet views, the wire is advanced ensuring the wire travels perpendicular to the plane of injury. In sacroiliac injuries, the wire travels from posterior to anterior on the inlet and inferior to superior on the outlet. Usually two screws are necessary to control rotation. Depending on the size of the osseous corridors, one screw can be placed in S1 and one in S2 or two in S1. A lag by technique or design method can be utilized in order to obtain compression. The screw length is measured and should terminate at the contralateral sacral ala. The size of the screw depends on the anatomy of the patient but is typically 6.5 mm or greater. The screw is placed over a washer in order to dissipate the forces over the outer table and prevent over-penetration, which will weaken the fixation strength. The pelvis is then stressed in order to determine if additional anterior fixation is necessary. Often times, anterior fixation is necessary to increase the overall strength of fixation. If the anterior injury is through the symphysis, fixation is obtained via an open reduction through a Pfannenstiel incision and internal fixation using a multi-hole 3.5 mm reconstruction plate and cortical screws. If the injury is through the ipsilateral rami, which is typical for vertical shear fractures, then a retrograde superior rami screw can be placed percutaneously as described by Roult et al. (1999). Both approaches require the patient positioned supine. In younger patients, such as the case presented, the periosteum may still be intact, and no further fixation is necessary.

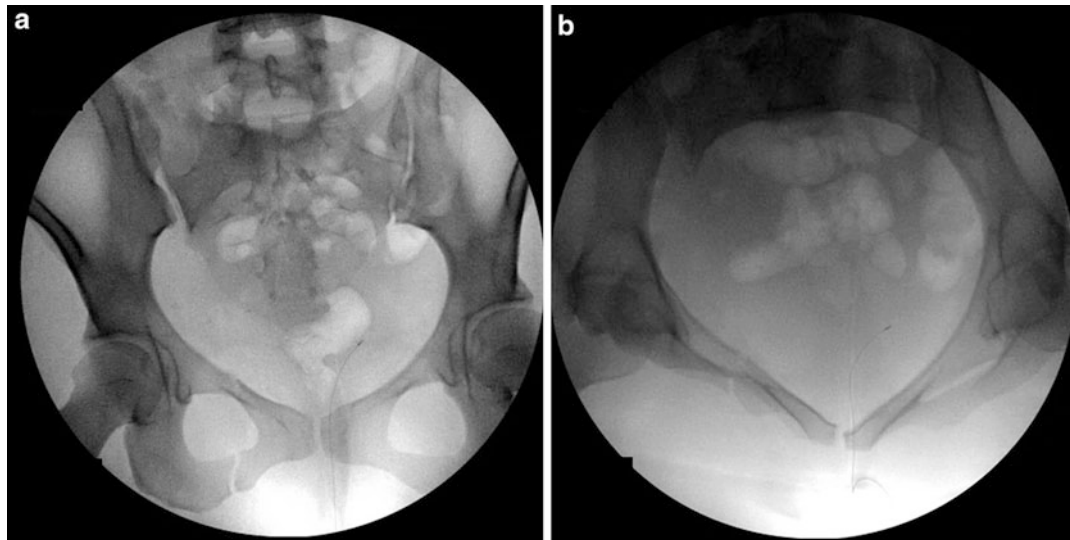


Fig. 5 (a) AP view demonstrating the vertical displacement of the right hemipelvis as seen by the incongruence of the right sacroiliac joint. Not uncommon for younger patients, with robust periosteum, the anterior ring injury is minimally displaced suggesting that the periosteum is still intact. (b) Inlet view demonstrating the anterior to posterior displacement of pelvic ring injuries as evident of the incongruence at

the right sacroiliac joint. Again note the minimally displaced rami fractures suggestive of intact periosteum. The images were taken prior to prepping the patient with the use of axial traction on the right hemipelvis indicating an irreducible right sacroiliac joint via closed methods

6 Images During Treatment

See Figs. 5, 6, 7, 8, and 9.

7 Technical Pearls

Successful reduction could not be obtained via closed methods, with the ilium remaining superior and posterior to the sacrum on fluoroscopy. The patient was positioned in the prone position, and a typical posterior approach to the right sacroiliac joint was utilized. Hematoma and early granulation tissue were cleaned. There was a small portion of sacrum that was fractured, which was used in conjunction with the sacroiliac joint to directly confirm reduction. Provisional stabilization was held with a Kirschner wire. Reduction was confirmed using orthogonal images. Attention was turned then to fixation. A lateral of the posterior pelvic ring was used to determine the appropriate starting point for the guidewire, and using the inlet and outlet, the wire was advanced until it terminated at the contralateral sacral ala. Care was made to insure the wire remained in the osseous corridors and that the trajectory was perpendicular to the sacroiliac joint. An additional wire was placed in S1. Two 6.5 partially threaded screws were then placed. Fluoroscopy was used to confirm successful reduction and compression as the screws were final tightened. The pelvis was then stressed and found to be stable and thus did not require anterior fixation.



Fig. 6 Outlet view taken intraoperatively with patient in the prone position after open reduction of the right sacroiliac joint. The outlet view is used to assess vertical displacement which has been reduced in the image

8 Outcome Clinical Photos and Radiographs

See Figs. 10, 11, and 12.



Fig. 7 Outlet view after instrumentation again demonstrating congruency of the right sacroiliac joint in the vertical plain. The following view is also used to ensure that the sacroiliac screws are extra-foraminal and traversing perpendicular to the sacroiliac joint with an inferior to superior trajectory



Fig. 9 Obturator oblique view is used to ensure that the screws have been fully seated on the ilium. Care should be taken to avoid over-penetration of the outer table which would negatively affect the strength of fixation

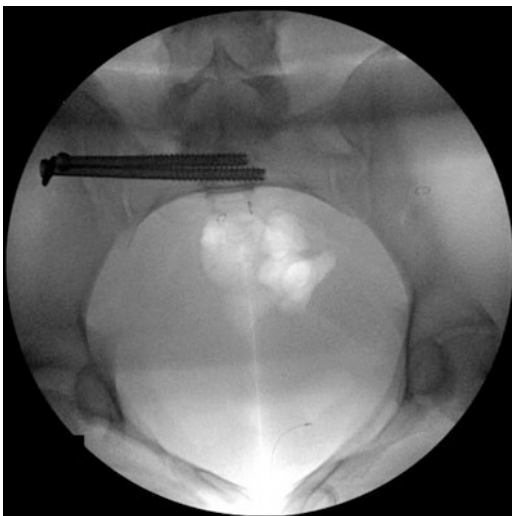


Fig. 8 Inlet view is used to assess the anterior to posterior displacement as well as the external or internal rotation deformity. The view is also used to ensure that the screws remain within the osseous corridor and not exiting out the sacral ala which would put the L5 nerve root at risk. The screws should once again be perpendicular to the sacroiliac joint, traveling from posterior to anterior



Fig. 10 AP at 5-month follow-up demonstrating healed fracture without evidence of hardware failure or loss of reduction. There is no evidence of a flexion/extension or external/internal rotation deformity

9 Avoiding and Managing Problems

A thorough evaluation is critical to avoid missed injuries and additional trips to the operating room. The skin should be examined for Morel-Lavallée or open wounds. The perineum should be examined for occult open fractures, rectal injury, and

genitourinary injury. Genitourinary injuries may require a retrograde urethrogram, urology consultation, and possible suprapubic catheter placement. Bladder injuries should be repaired prior to or the time of surgery. Rectal injury may require diverting colostomy. Thorough documentation of neurologic function in the affected limb is critical both preoperatively and postoperatively. Foot drop should be managed with an orthosis until neurologic function returns in order to avoid equinus contracture. Aggressive bowel regimen and avoidance of gaseous anesthesia aid in obtaining unobstructed intraoperative images (Barei et al. 2001). Sacral dysmorphism should be noted preoperatively as this may affect the availability of safe



Fig. 11 Inlet view at 5-month follow-up demonstrates maintained reduction in terms of anterior posterior displacement and external/internal rotation deformity

osseous corridors (Kaiser et al. 2014). Changes in neurologic examination postoperatively should be followed by a CT scan to assess for penetration of the instrumentation through the sacral ala or sacral foramina and if present warrants a repeat trip to the operating room for revision of instrumentation. Poor outcomes are directly correlated with neurologic dysfunction, genitourinary injury, leg length discrepancy >2.5 cm, and malreduction of the sacroiliac joint (Tornetta and Matta 1996).

10 Cross-References

- [Acetabulum Fracture with Closed Triradiate](#)
- [Pubic Symphysis Disruption](#)



Fig. 12 Outlet view at 5-month follow-up demonstrates maintained reduction in terms of vertical displacement

References and Suggested Reading

- Barei DP, Bellabarba C, WJ M, Routt ML Jr (2001) Percutaneous management of unstable pelvic ring disruptions. *Injury* 32(Suppl 1): SA33–SA44
- Kaiser SP, Gardner MJ, Liu J, Routt ML Jr, Morshed S (2014) Anatomic determinants of sacral dysmorphism and implications for safe iliosacral screw placement. *J Bone Joint Surg* 16(14):e120
- Routt ML, Simonian PT, Mills WJ (1997) Iliosacral screw fixation: early complications of the percutaneous technique. *J Orthop Trauma* 11(8):583–589
- Routt ML, Simonian PT, Grujic L (1999) The retrograde medullary superior pubic ramus screw for the treatment of anterior pelvic disruptions. *J Orthop Trauma* 1:35–44
- Tornetta P 3rd, Matta JM (1996) Outcome of operatively treated unstable posterior pelvic ring disruptions. *Clin Orthop Relat Res* 329:186–193

Acetabulum Fracture with Closed Triradiate

Omar H. Atassi and Jaclyn F. Hill

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Abstract

Acetabulum fractures in pediatric patients are rare injuries usually occurring after closure of the triradiate cartilage. They occur almost exclusively following high energy trauma and thus a thorough primary and secondary survey is necessary to assess for associated injuries. Examination of the genitourinary system and neurovascular status is critical. Aggressive resuscitation and stabilization should occur during the hospitalization, and multiple services including general surgery, urology, and orthopedic surgery may be necessary for optimal management. Classification is best described using the Letournel Classification. The

need for operative intervention increases after triradiate closure. Definitive surgical management should occur within the first week, once the patient has been adequately resuscitated, preoperative imaging and planning has been completed, and all personal and equipment is available. Blood products should be available during the procedure. Various patient position and surgical approaches are utilized depending on the fracture pattern and soft tissue status. Obtaining excellent fluoroscopic images is necessary during the procedure. Articular reduction is critical to obtaining successful outcomes. Malreduction and associated genitourinary and neurologic injuries are directly related to poor long-term outcomes.

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1 Brief Clinical History

The patient is a 16-year-old boy who presented after a dirt-bike accident with leg pain and deformity. Patient is stable alert and interactive. The right leg is externally rotated with a thigh hematoma and two poke holes in the posterior thigh.

The patient experienced pain in the left groin with log roll. Pelvis exam was stable but painful with rotation. No perineal wounds were noted. Skeletal survey did not reveal any other potential injuries. He was neurologically intact to motor and sensory exam in all four extremities. He had no other associated injuries.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, 5.

3 Preoperative Problem List

1. Right grade IIIa open subtrochanteric femur fracture
2. Left T-type acetabulum fracture

4 Treatment Strategy

A primary and secondary survey followed by a delayed tertiary survey is necessary to identify all injuries. The patient requires aggressive resuscitation upon presentation and particularly during the second inflammatory hit. Open fractures require immediate intravenous antibiotics and bedside irrigation followed by urgent surgical irrigation and debridement. Neurovascular injuries must be identified and managed appropriately. As the sciatic nerve exits the pelvis through

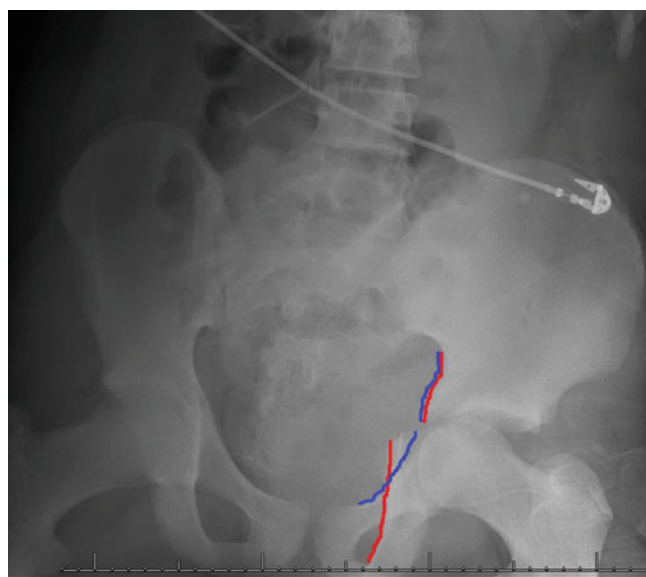


Fig. 1 AP x-ray demonstrates left acetabulum fracture with mild femoral protrusion. Disruption of the ilioischial (*red*) and iliopectineal (*blue*) lines indicates injury to both anterior and posterior column of the acetabulum

the greater sciatic notch, it courses near the posterior exit point of the transverse fracture. Long bone fractures of the femur and tibia should be managed urgently to aid in the resuscitative process and prevent pulmonary complications. The femur fracture was stabilized with a reconstructive intramedullary nail within 24 h from presentation. The acetabulum fracture may require skeletal traction in the interim if there is protrusion, posterior subluxation/dislocation, loose bodies, or articular step off along the weight bearing portion of the acetabulum. Further imaging, including Judet, inlet/outlet, and CT reconstruction, may be obtained for surgical planning. The patient is ready for surgery once the patient is adequately resuscitated and the proper equipment and personnel are available.

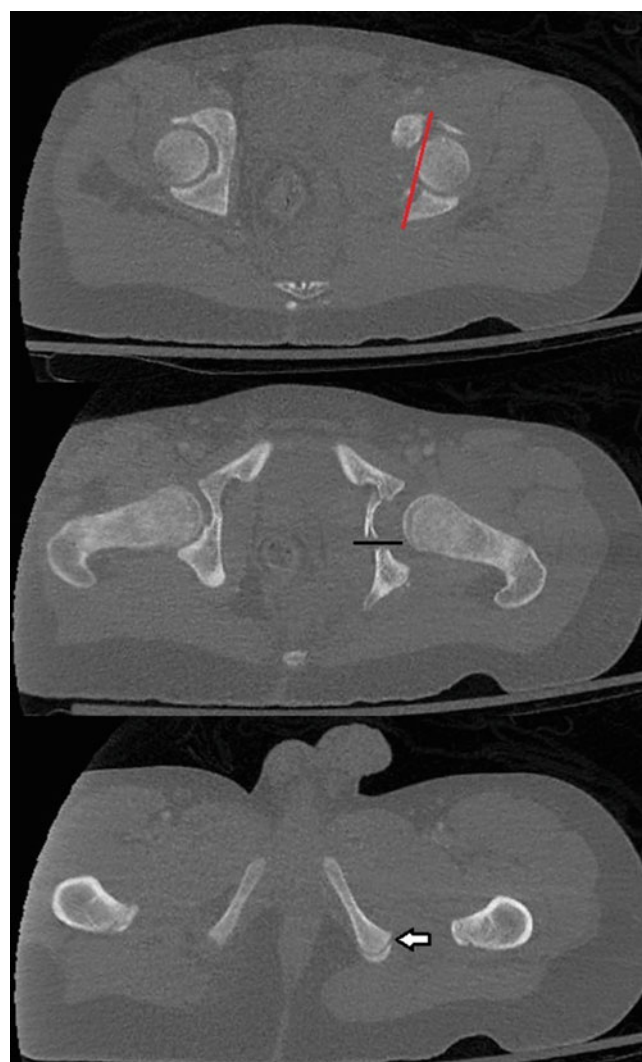


Fig. 2 Axial cut demonstrates a vertical fracture line (*red*) associated with a transverse fracture and a horizontal fracture line (*black*) associated with column fracture. Moving inferiorly, the column fracture will exit the inferior rami or ischial tuberosity (*arrow*). The presence or absence of marginal impaction should also be identified



Fig. 3 3D reconstruction oblique view demonstrating a left T-type acetabulum fracture. A transverse fracture is extending across both the anterior and posterior columns. The transverse component is transtectal, as it is traversing through the weight-bearing portion of the acetabulum. A separate vertical fracture is separating both columns from one another



Fig. 4 3D reconstruction posterior view demonstrates where the transverse fracture exits posteriorly

5 Basic Principles

T-type acetabulum fractures are typically approached through a posterior Kocher-Langenbeck approach, as the posterior column is more displaced or associated with a posterior wall component. In some cases, such as significant anterior column displacement, a separate anterior incision (ilioinguinal) or an extensile incision (trochanteric osteotomy, extended iliofemoral) may be necessary. Separate or more extensile incisions carry morbidity. Care should be

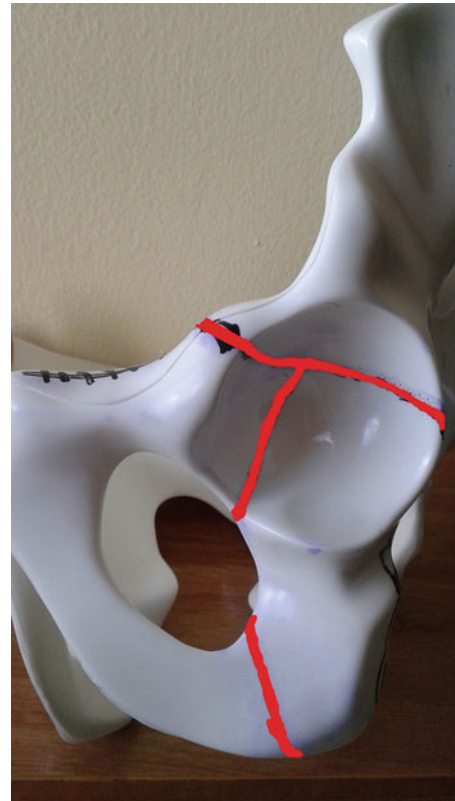


Fig. 5 A pelvis model can help in pre-operative planning, particularly given the complex osteology of the pelvis

made to identify the sciatic nerve and note any contusion or injury to the nerve which may be seen with acetabulum fractures, particularly associated with dislocation. Necrotic muscle, usually the gluteus minimus, should be excised, for heterotopic ossification prophylaxis. The fracture is distracted and cleaned of hematoma and early granulation tissue. The joint can be distracted to remove loose bodies and to assess for marginal impaction. The posterior column is addressed first. The fracture can be reduced with various clamps including Jungbluth, Weber, or large pointed reduction. Depending on the fracture pattern, one end of the clamp may have to buttress against the quadrilateral surface and thus be working through the greater sciatic notch. Careful attention to the sciatic nerve must be made at all times. Fracture reduction can be assessed with direct visualization and with fluoroscopy. Once reduction is confirmed, a well-contoured 3.5-mm reconstruction plate should be placed posteriorly. The caudal screws should aim into the ischium and the cranial screws into the supra-acetabular region. Attention is then turned to the anterior column. If the fracture is infratectal or nondisplaced, it can be stabilized in situ or treated without further stabilization. If displaced, the fracture can be reduced and clamped through the posterior incision using pointed reduction or Weber clamps. Reduction is assessed indirectly with fluoroscopy. If reduction cannot be

obtained, a separate anterior or extensile approach may be necessary. Once the fracture is reduced, a partially threaded anterograde anterior column screw can be placed. Various size screws can be used depending on the patient's anatomy. Standard closure should follow. The external rotators should be re-approximated. A subfascial drain can be placed. The fascia is closed tightly followed by the skin.

6 Images During Treatment

See Fig. 6.

7 Technical Pearls

The patient was positioned in the right lateral decubitus position and a Kocher-Langenbeck approach was utilized. The sciatic nerve was identified and found to be severely contused. The fracture was distracted with a Shantz pin in the ischial tuberosity and debrided. A Steinmann pin was placed into the distal femur to distract the joint and assess for marginal impaction and loose bodies. A Jungbluth clamp was used to reduce the fracture which was confirmed with direct visualization and fluoroscopy (iliac oblique view). A 3.5-mm reconstruction plate was placed posteriorly. The plate should be contoured to compress the anterior component of the posterior column fracture. The anterior column was then reduced with a Weber clamp and a percutaneous 6.5 partially threaded cannulated screw was placed anterograde from the medial gluteal pillar to the superior pubic rami. Care should

be made to insure the trajectory of the screw is perpendicular to the fracture line, as an oblique screw trajectory and compression may then displace the fracture. Proper trajectory of the anterior column screw was assessed with inlet view and obturator oblique views.

8 Outcome Clinical Photos and Radiographs

See Figs. 7, 8, 9, 10 and 11.

9 Avoiding and Managing Problems

A thorough evaluation is critical to avoid missed injuries and additional trips to the operating room. The skin should be examined for Morel Lavellée soft tissue injuries or open wounds. The perineum should be examined for occult open fractures, rectal injury, and genitourinary injury. Genitourinary injuries may require a retrograde urethrogram, urology consultation, and possible supra-pubic catheter placement. Bladder injuries should be repaired prior to or at the time of surgery (Wathik et al. 1996). Rectal injury may require diverting colostomy. In cases of protrusion or dislocation, repeat radiographs of the pelvis should be obtained each time the patient is transported back into their bed, as the femoral head may dislocate during transfers as traction is removed. Thorough documentation of neurologic function in the affected limb is critical both pre- and postoperatively. Foot drop should be managed with an orthosis until



Fig. 6 Intraoperative obturator oblique view demonstrating reduction of the anterior column and anterior column screw remaining extra-articular and within an osseous tunnel

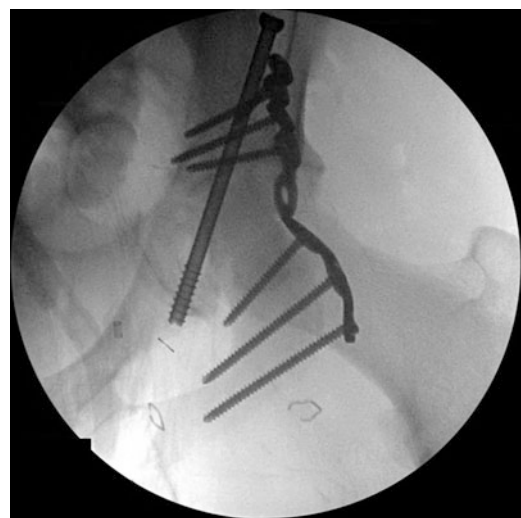


Fig. 7 AP pelvis 8 weeks postoperatively demonstrates interval callus formation. Hardware intact without loosening. Femoral head remains concentrically reduced



Fig. 8 Judet iliac oblique assessing the reduction of the posterior column



Fig. 10 Judet iliac oblique of the left hip assessing the reduction of the posterior column. Noted is the interval healing of the fracture and heterotopic ossification of the right greater trochanter



Fig. 9 A rotated AP pelvis demonstrates restoration of the ilioischial and iliopubic lines. Also noted is the interval healing of the left acetabulum fracture



Fig. 11 Judet obturator oblique of the left hip assessing the reduction of the anterior column. Noted is interval healing of the fracture and heterotopic ossification on the *left* and over the *right* greater trochanter

neurologic function returns in order to avoid equinus contracture. Aggressive bowel regimen and avoidance of gaseous anesthesia aids in obtaining unobstructed intraoperative images (Barei et al. 2001). Heterotopic ossification (HO) prophylaxis is still a subject of debate. Prophylaxis options include external beam radiation pre- or postoperatively or indomethacin (Firoozabadi et al. 2017). More extensive surgical approaches, head injuries, and poly-trauma are also associated with increased HO risk. Debridement of necrotic muscle intraoperatively, particularly the gluteus

minimus, has been found to be helpful in decreasing the risk of HO (Rath et al. 2002).

10 Cross-References

- [Hip Dislocation with Acetabular Fracture](#)
- [Pubic Rami Fracture with Disruption of the Sacroiliac Joint \(Malgaigne Fracture\)](#)

References and Suggested Reading

- Barei DP, Bellabarba C, Mills W, Routt ML Jr et al (2001) Injury 32 (Suppl 1):SA33–SA44
- Firoozabadi R, Alton T, Sagi HC (2017) Heterotopic ossification in acetabular fracture surgery. JAAOS 25(2):117–124
- Rath EM, Russel GV Jr, Washington WJ, Routt ML Jr (2002) Gluteus minimus necrotic muscle debridement diminishes heterotopic ossification after acetabular fracture fixation. Injury 33(9):751–756
- Wathik NF, Coburn M, Goldberger M (1996) Urologic injuries in pelvic ring disruptions. Clin Orthop Relat Res 329:37–45

Hip Dislocation

Kenneth Bono

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Abstract

Hip dislocations in children are rare, potentially occurring after falls, athletic injuries, or high energy mechanisms such as car accidents. When they occur in the setting of a high mechanism of energy, they can be associated with other head, chest, abdominal, and neurovascular injuries. Associated orthopedic injuries can include ipsilateral femoral neck, femoral shaft, or acetabular fractures, as well as loose bodies within the hip joint. Many times a closed reduction can sufficiently treat a hip dislocation, but one must be prepared to potentially perform an open reduction, particularly in the setting of associated fractures. Urgent reduction within 6 h is recommended in an effort to minimize the risk of avascular necrosis in these patients.

1 Brief Clinical History

An 8-year-old male, unrestrained backseat passenger, was involved in a roll over motor vehicle crash after their car was struck by another vehicle at around 40–50 miles per hour. He denied loss of consciousness, and was only complaining of right hip pain upon presentation to the emergency room, and was noted to be holding his right hip in a flexed, abducted, and externally rotated position. He was evaluated by the trauma service and found to be stable. X-rays demonstrated an anterior right hip dislocation, without any fractures or loose bodies noted. No other injuries were identified, and he was noted to be neurovascularly intact distally in his right lower extremity.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

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3 Preoperative Problem List

Anterior right hip dislocation.

4 Treatment Strategy

After being evaluated by the trauma team, it was felt that he was stable to undergo conscious sedation and closed reduction of the dislocation. X-rays did not demonstrate any



Fig. 1 AP pelvis radiograph demonstrates a right hip anterior dislocation, and absence of fractures



Fig. 2 Lateral right hip radiograph does not demonstrate any femoral neck fractures

femoral neck fractures that could potentially be displaced during a closed reduction. Special attention was made to ensure that it was a deep sedation to maximize muscular relaxation. Gentle reduction was performed with traction, lateralization of the proximal femur, adduction, and internal rotation until gentle seating of the femoral head in the acetabulum was felt. Following the reduction, x-rays demonstrated a reduced right hip. Subsequent CT scan was obtained to confirm a concentric reduction, and rule out the presence of any associated fractures or loose bodies within the hip joint. He was then admitted to the hospital for observation on the trauma service to monitor for any other potential injuries given the high energy of the accident he was involved in. While in the hospital, anterior hip dislocation precautions were reviewed by physical therapy in hopes of reducing the possibility of redislocation.

5 Basic Principles

Hip dislocations can occur in the setting of low or high energy mechanisms of injury. When associated with high energy mechanisms, additional injuries must be ruled out. Approximately, 90% of hip dislocations are posterior, with the remaining 10% being anterior. Adequate imaging of the proximal femur and hip are necessary prior to attempted reductions to rule out associated injuries such as a femoral neck fracture that could displace during closed reduction. If these injuries are identified, open reduction should be considered, with fixation across the femoral neck fracture prior to reduction of the hip. A thorough neurovascular exam should be performed before and after reduction to rule out associated neurovascular injury which is often seen in the setting of hip dislocations.

Outcomes following hip dislocations in children have been correlated to the amount of energy exerted during the injury. Higher mechanisms of energy are associated with higher risks of avascular necrosis.

6 Images During Treatment

See Figs. 3, 4, 5, 6, and 7.

7 Technical Pearls

Deep sedation or a general anesthetic is necessary to ensure good muscular relaxation to decrease the likelihood of iatrogenic fracture that may occur if a gentle controlled reduction is not possible because of the child's muscle spasm.

CT scan should be obtained after hip reduction to confirm concentric reduction, and rule out loose bodies in the joint, or



Fig. 3 Postreduction AP pelvis radiograph demonstrating apparent concentric reduction of the right hip



Fig. 4 CT scan coronal image demonstrates reduced right hip with no fractures or loose bodies

associated fractures of the femoral head or neck, or acetabular fractures that may require further treatment.

Time to reduction of less than 6 h has been associated with a lower risk of avascular necrosis, and improved overall outcomes.

Open reduction may be required if attempted closed reduction is unsuccessful. The approach should allow for access to clear structures that may be interposed, thus blocking reduction. Therefore, a standard posterior approach (Southern or Moore) should be considered for posterior dislocations, and an anterior (Smith-Peterson) or anterolateral (Watson-Jones) approach should be considered for anterior dislocations. In addition, one should also take into account if



Fig. 5 CT scan axial images demonstrate reduced right hip with no fractures or loose bodies (Fig. 5 is the most proximal slice through the femoral head, Fig. 6 is through the midportion of the femoral head, and Fig. 7 in more inferior through the femoral neck. All three images also visualize the acetabulum, and do not demonstrate any fractures)

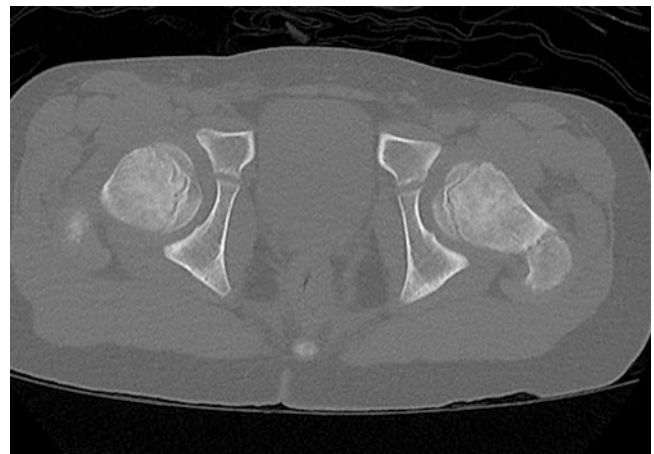


Fig. 6 CT scan axial images demonstrate reduced right hip with no fractures or loose bodies (Fig. 5 is the most proximal slice through the femoral head, Fig. 6 is through the midportion of the femoral head, and Fig. 7 in more inferior through the femoral neck. All three images also visualize the acetabulum and do not demonstrate any fractures)

a given approach will sufficiently allow for visualization and access to address any other additional fractures that may require open reduction and internal fixation such as femoral head or acetabular fractures.

8 Outcome Clinical Photos and Radiographs

See Figs. 8 and 9.

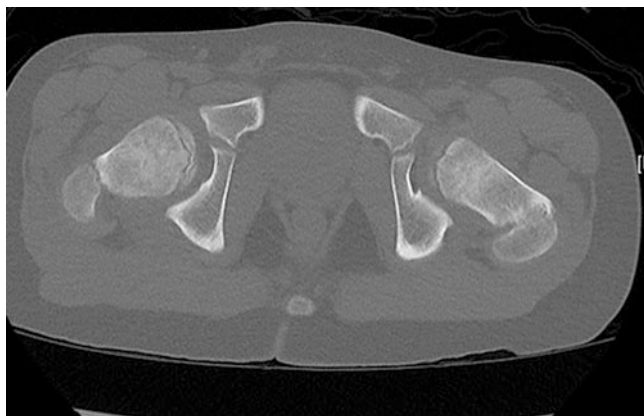


Fig. 7 CT scan axial images demonstrate reduced right hip with no fractures or loose bodies (Fig. 5 is the most proximal slice through the femoral head, Fig. 6 is through the midportion of the femoral head, and Fig. 7 in more inferior through the femoral neck. All three images also visualize the acetabulum and do not demonstrate any fractures)



Fig. 8 AP pelvis radiograph 18 months post-reduction does not demonstrate any signs of avascular necrosis



Fig. 9 Frog lateral radiograph 18 months post-reduction does not demonstrate any signs of avascular necrosis

Postreduction CT should be closely scrutinized to rule out the presence of an incongruous reduction, or entrapped loose bodies, or associated acetabular, femoral neck, or head fractures that may require open reduction and internal fixation.

There is no consensus regarding immobilization after hip dislocations. Consideration should be given to avoid provocative maneuvers or positioning that may lead to redislocation. Usually this involves approximately 4–6 weeks of immobilization or protective weight-bearing to allow for soft tissues and any fractures to begin healing. This is then typically followed by progressive range of motion and progressive weight-bearing over the subsequent few weeks until full pain free range of motion is obtained, after which the child can progressively return to activity as tolerated. Depending on the age of the child, and expected compliance, this may require spica casting in very young children, and consideration for bracing or limited activity in older children.

One must educate the patient and their family about the potential risk of avascular necrosis, including the possibility that it may not present or cause symptoms for a couple years following the original injury.

9 Avoiding and Managing Problems

One cannot alter the energy of the mechanism of injury, but they can potentially reduce the risk of avascular necrosis by reducing the hip within 6 h of dislocation.

Adequate imaging to rule out potential femoral neck fracture prior to attempted closed reduction to reduce the potential for iatrogenic displacement of the femoral neck fracture, which would further increase the potential for avascular necrosis.

10 Cross-References

- [Hip Dislocation with Acetabular Fracture](#)
- [Hip Dislocation with Proximal Femoral Physeal Fracture](#)

References and Suggested Reading

- Herrera-Soto JA, Price CT (2009) Traumatic hip dislocations in children and adolescents: pitfalls and complications. *J Am Acad Orthop Surg* 17(1):15–21. Review
- Mehlman CT, Hubbard GW, Crawford AH, Roy DR, Wall EJ (2000) Traumatic hip dislocation in children. Long-term followup of 42 patients. *Clin Orthop Relat Res* 376:68–79
- Swiontkowski M, Li M (2015) Fractures and dislocations about the hip and pelvis. In: Green's skeletal trauma in children, 5th edn. Elsevier, Philadelphia, pp 311–364

Hip Dislocation with Acetabular Fracture

John B. Erickson and Kevin E. Klingele

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Abstract

Traumatic dislocation of the hip is a rare injury in the pediatric and adolescent population. Management of this injury revolves around obtaining a stable and concentric reduction of the hip joint. This can typically be accomplished via closed means with reduction in either the emergency department or the operating room. If an attempt at closed reduction is unsuccessful, or results in a noncongruent hip joint, then surgical intervention is warranted. Recent studies have shown a high incidence of concomitant posterior labral pathology that may require surgical treatment. Associated injuries can include femoral head fractures, acetabular fractures, femoral head or acetabular cartilage delamination, and labral detachments. This case presents the management

strategy for a 14-year-old male with a right hip dislocation and associated osteochondral avulsion of the posterior labrum.

1 Brief Clinical History

A 14-year-old male presents to the emergency department with complaint of right hip pain after being tackled during a football game. On physical exam, his right lower extremity is held in a shortened and internally rotated position. No other injuries are noted, and his neurovascular exam is intact. Radiographs demonstrate a right posterior hip dislocation with a posterior acetabular wall fragment (Fig. 1). The patient undergoes closed reduction of the right hip under conscious sedation in the emergency department. Postreduction radiographs and computed tomography (CT) scan demonstrate a nonconcentric reduction with entrapment of the posterior labrum osteochondral avulsion, consistent with an acetabular “fleck sign” (Blanchard et al. 2016) (Fig. 2a, b).

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2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Right posterior hip dislocation
2. Right posterior labrum osteochondral avulsion injury
3. Skeletally immature proximal femur

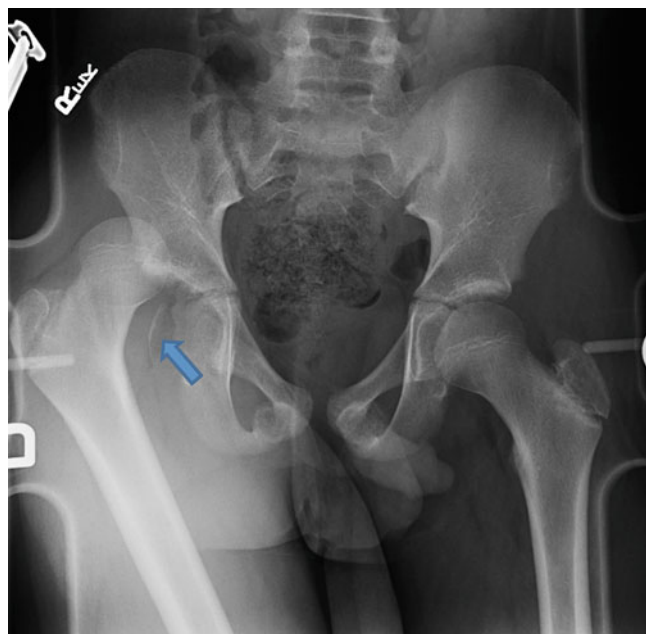


Fig. 1 AP pelvis radiograph at presentation demonstrating a right posterior hip dislocation (*arrow*) with posterior acetabular wall fragment

4 Treatment Strategy

Management of this injury requires obtaining a stable and concentric reduction of the patient's hip joint. This can typically be accomplished via closed means with reduction in either the emergency department or operating room. It is important to perform the reduction under adequate sedation to minimize additional trauma to the femoral epiphysis and acetabular labrum. Postreduction imaging should include plain radiographs as well as CT and/or magnetic resonance imaging (MRI) studies of the pelvis. These advanced imaging techniques are necessary to assess the hip joint congruency and to evaluate the femoral head, acetabulum, and labrum for any associated injuries. MRI should be considered in skeletally immature patients as it has been shown to provide a better assessment of associated soft tissue injuries and injuries involving the nonossified portion of the pelvis and femoral head in this population (Mayer et al. 2015). Postreduction CT imaging in this case demonstrates a nonconcentric hip reduction with a displaced acetabular fleck sign. Treatment strategy for this patient includes an open, surgical intervention in the form of a surgical hip dislocation (SHD) approach with removal and repair of the incarcerated posterior wall osteochondral labral avulsion.

5 Basic Principles

Patients presenting with a hip dislocation require urgent treatment and reduction (<6 h from time of injury) to reduce the risk of femoral head avascular necrosis (AVN) (Mehlman et al. 2000). If closed reduction is unsuccessful, or results in a noncongruent hip joint, surgical intervention is warranted. The surgical approach for open reduction is typically guided by the direction of the dislocation. Anterior dislocations are typically addressed via the Smith-Petersen approach and

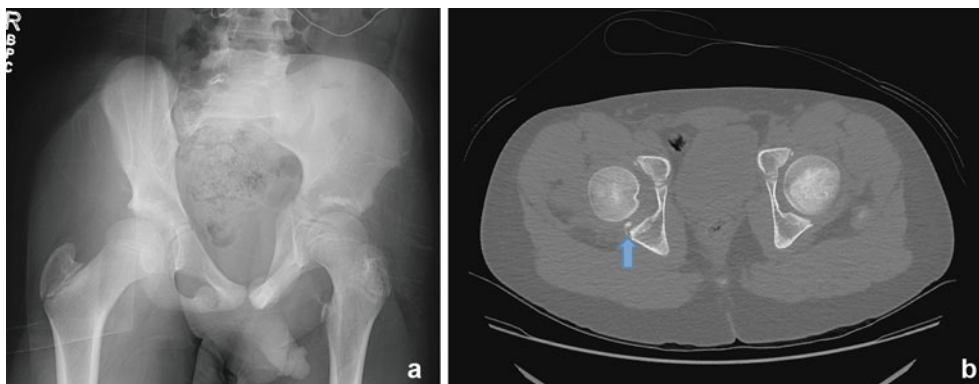


Fig. 2 Postreduction AP pelvis (**a**) and CT scan (**b**) images demonstrating nonconcentric reduction (**a**) with entrapment of the posterior labrum osteochondral avulsion (**b**) consistent with a positive acetabular "fleck sign" (*arrow*)

posterior dislocations via the Kocher-Langenbeck approach. Alternatively, the surgical hip dislocation approach has been shown to be safe and effective in the treatment of pediatric and adolescent traumatic hip dislocations with nonconcentric reduction, residual instability, associated intra-articular fractures, and/or labral tears (Podeszwa et al. 2015; Novais et al. 2016; Blanchard et al. 2016).

6 Images During Treatment

See Figs. 3 and 4.

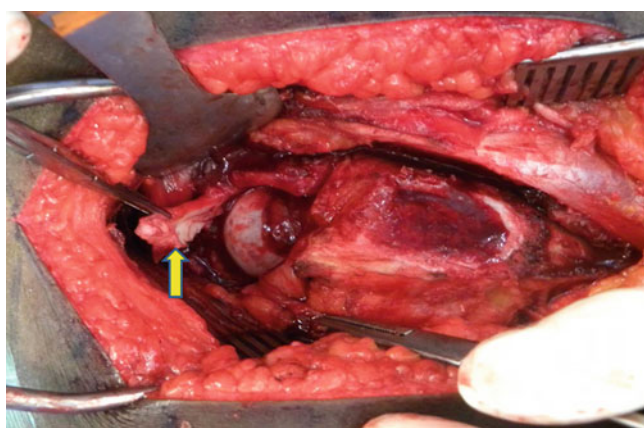


Fig. 3 Intraoperative image of posterior, osteochondral labral avulsion, seen through SHD approach



Fig. 4 Postoperative AP radiograph demonstrating congruent hip reduction SHD with ORIF of posterior labrum osteochondral avulsion

7 Technical Pearls

When performing a surgical hip dislocation approach in the setting of a hip dislocation it is important to note that there will most likely be an existing traumatic arthrotomy of the hip joint. This traumatic arthrotomy most often allows the incorporation of a large posterior capsular flap and thus protection of the piriformis tendon and vascular supply to the femoral head. After dislocation of the femoral head, the femoral head and acetabulum should be inspected for additional fractures and/or chondral injuries and treated appropriately. The ligamentum teres is often avulsed or attenuated and can be resected to aid in reduction of the hip. Hip dislocations with an associated acetabular fracture can also be treated via this approach. In pediatric and adolescent patients with an associated posterior wall fracture, the fracture typically involves an osteochondral fragment comprised of nonossified cartilage that is avulsed from the posterior acetabular wall along with the posterior labrum. Fixation technique for this injury depends on the size of the fragment. Reattachment of smaller osteochondral labral avulsions can be performed with suture anchors placed along the posterior rim of the acetabulum. Fragments with a large osseous portion can be reduced and fixed with 3.5 mm screws with additional suture anchor fixation if needed (Fig. 5). Large posterior wall fractures are rare in the pediatric and adolescent population. However, if a patient has a large posterior wall fracture that requires direct reduction and plate fixation, extending the approach in both directions can be achieved. Utilization of the surgical hip dislocation approach allows direct visualization of the acetabulum during anchor and screw placement. This allows the



Fig. 5 AP radiograph demonstrating fixation utilizing small frag 3.5 mm screws

surgeon to verify extra-articular placement of any screws or anchors placed. Postoperative treatment is on a patient-by-patient basis, but typically involves a period of protected weight-bearing with early mobilization.

8 Outcome Clinical Photos and Radiographs

See Fig. 5.

9 Avoiding and Managing Problems

It is important to treat these injuries in an urgent manner. Closed reduction should be performed as soon as possible to reduce the risk of AVN. Reduction under fluoroscopy may be beneficial if there is concern for a nondisplaced physeal fracture of the femoral head. The fluoroscopy may help to avoid any displacement and further vascular insult to the femoral head epiphysis. If postreduction imaging demonstrates a nonconcentric reduction, the patient should be taken to the operating room for open reduction of the hip joint. If surgery is to be delayed for more than a couple of hours, the patient should be placed into traction to help decompress the hip joint and prevent further damage to the articular cartilage. This is of particular importance in patients with entrapment of an osteochondral fragment within the joint. Careful evaluation of the postreduction CT and/or MRI is critical for preoperative planning and to ensure

required implants are available at the time of surgery. Postoperatively, it is important to follow the patient radiographically for at least 12–18 months to monitor for the development of AVN.

10 Cross-References

- ▶ [Acetabulum Fracture with Closed Triradiate](#)
- ▶ [Hip Dislocation](#)
- ▶ [Hip Dislocation with Proximal Femoral Physeal Fracture](#)

References and Suggested Reading

- Blanchard C, Kushare I, Boyles A, Mundy A, Beebe AC, Klingele KE (2016) Traumatic, posterior pediatric hip dislocation with associated posterior labral osteochondral avulsion: recognizing the acetabular “fleck” sign. *J Pediatr Orthop* 36:602–607
- Mayer SW, Stewart JR, Fadell MF, Kestel L, Novais EN (2015) MRI as a reliable and accurate method for assessment of posterior hip dislocation in children and adolescents without the risk of radiation exposure. *Pediatr Radiol* 45:1355–1362
- Mehlman CT, Mast NH, Ganz R et al (2000) Traumatic hip dislocation in children. Long-term follow up of 42 patients. *Clin Orthop Relat Res* 376:68–79
- Podeszwa DA, Rocha AD, Larson AN, Sucato DJ (2015) Surgical hip dislocation is safe following acute traumatic hip instability in the adolescent. *J Pediatr Ortho* 35:435–442
- Novais EN, Heare TC, Hill MK, Mayer SW (2016) Surgical hip dislocation for the treatment of intra-articular injuries and hip instability following traumatic posterior dislocation in children and adolescents. *J Pediatr Orthop* 36:673–679

Hip Dislocation with Proximal Femoral Physeal Fracture

Craig Smith and Kevin E. Klingele

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Abstract

Proximal femoral physeal injuries with an associated hip dislocation are uncommon, potentially devastating injuries in the pediatric population. This is frequently the result of high-energy trauma; most commonly reported are motor vehicle collisions. It is important to therefore evaluate the whole patient for multisystem injuries. Due to the physeal injury, there is a significant risk for the development of avascular necrosis. This case highlights management of a proximal femoral physeal fracture/dislocation in a 12-year-old male involved in a motocross accident with special attention placed on surgical approach and avoidance of complications.

1 Brief Clinical History

A 12-year-old male presented as a transfer from another hospital after being involved in a high-speed motocross accident. He was evaluated as a level 1 trauma transfer due to mechanism. He was found to have an isolated injury with severe, left hip pain. Past medical history was noncontributory.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Left proximal femur physeal separation
2. Left posterior hip dislocation
3. Possible osteochondral labral avulsion

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Fig. 1 AP pelvis (a) and frog-leg (b) radiographs of the left hip demonstrate a Salter I fracture of the proximal femur with associated posterior dislocation of the femoral head

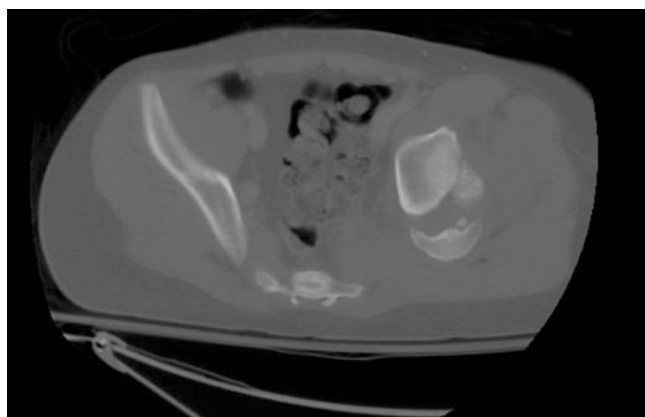
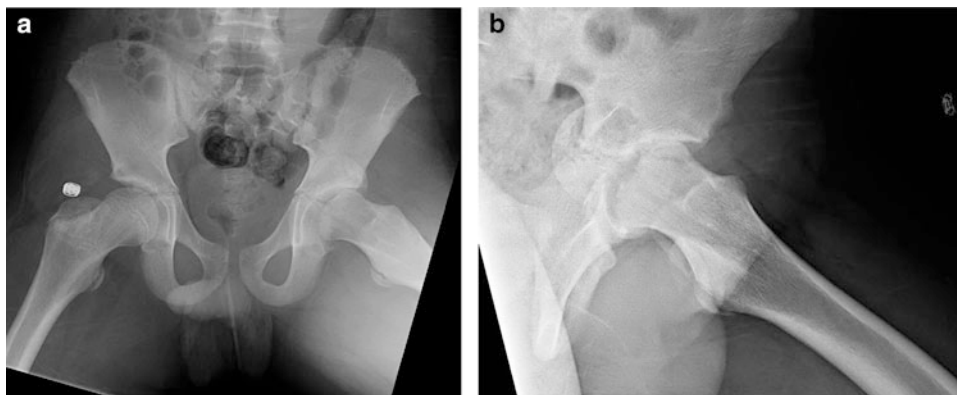


Fig. 2 CT scan pelvis demonstrates fracture with posterior dislocation of the proximal femur epiphysis

4 Treatment Strategy

Emphasis should be placed on initial resuscitation and management of any severe, non-orthopedic injuries. Once stabilized, urgent management of the severe hip injury can be prioritized. Multiple reports suggest a significant risk of avascular necrosis associated with this injury pattern (Walls 1992). Timing of reduction may influence this risk making urgent treatment necessary (Kellam et al. 2016). The goals of treatment include anatomic reduction, maintenance of reduction, assessment of associated injuries, and minimization of complication risks. Due to the definite need for surgical fixation, no attempt at closed reduction in the emergency room is indicated unless a delay to the operating room is expected. Options for operative intervention include a traditional posterior approach to the hip using a Kocher-Langenbeck approach versus a surgical hip dislocation (SHD) approach with greater trochanteric osteotomy. Due to concerns for disruption of the femoral head blood supply through a posterior approach, the surgical hip dislocation approach can provide adequate exposure

without further injury to the vascular supply to the involved hip (Ganz et al. 2001).

Urgent surgical management and general anesthesia are indicated. The patient is placed in the lateral decubitus position, and a posterior lateral incision based over the greater trochanter is utilized. Standard surgical hip dislocation (SHD) approach reveals both fracture site and dislocation, once the greater trochanter is mobilized anteriorly and the capsular tear extended with maintenance of a large posterior capsular flap. The femoral epiphysis is provisionally reduced to the femoral neck under direct visualization, while the hip remains dislocated. The posterior retinacular flap and periosteal sleeve should be preserved. A single-threaded 2 mm Kirschner wire is placed antegrade thru the fovea of the epiphysis, brought through the lateral, proximal femur and cut flush with the femoral head. A second, smooth 2 mm wire is placed retrograde across the physis for additional provisional fixation. This allows the hip to be safely reduced following assessment and management of any posterior labral pathology. In this case, a posterior osteochondral labral avulsion was repaired via suture anchor technique along the posterior acetabular rim. A full 360-degree view of both the femoral head and acetabulum is able to be achieved with this approach. The hip is then reduced and the smooth K-wire exchanged for a single 6.5 mm or 7.3 mm cannulated screw placed within the central portion of the epiphysis. After repair of the capsular tear and extended capsulotomy, the trochanteric wafer is reduced and held with two 3.5 mm fully threaded cortical screws. The patient is placed in a temporary abduction pillow until a formal brace can be fabricated.

5 Basic Principles

Obtaining and maintaining an anatomic reduction while being careful to protect the blood supply of the femoral head are key to a good outcome. With either the posterior approach or the surgical hip dislocation approach, one

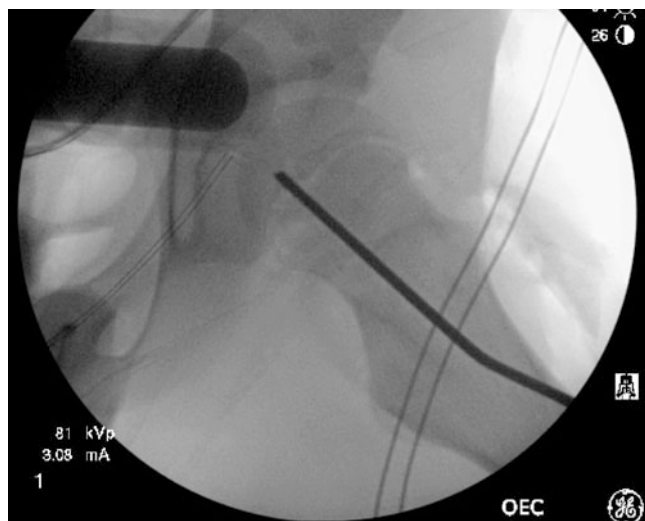


Fig. 3 Intraoperative fluoroscopy showing threaded K-wire fixation thru the fovea after reduction of the femoral head, subsequent reduction of dislocation, and removal of smooth K-wire supplementation

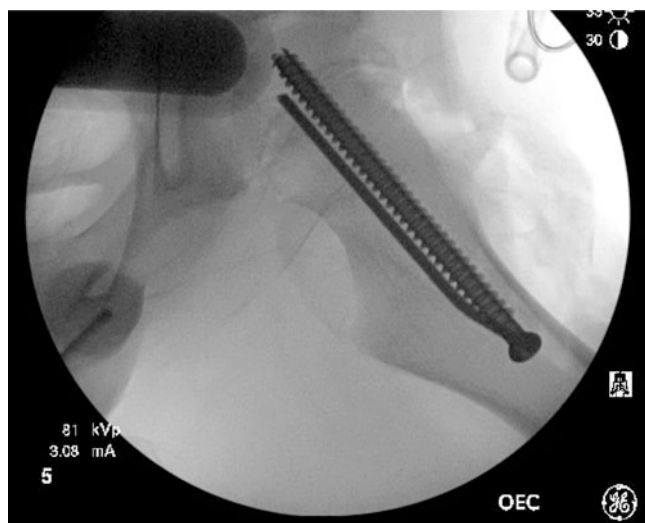


Fig. 4 Intraoperative fluoroscopy showing additional fixation with a 7.3 mm cannulated screw, placed retrograde into the central portion of the femoral epiphysis

must be vigilant with a good understanding of anatomy and careful dissection to avoid an iatrogenic injury to the vascular supply.

6 Images during Treatment

See Figs. 3, 4, and 5.

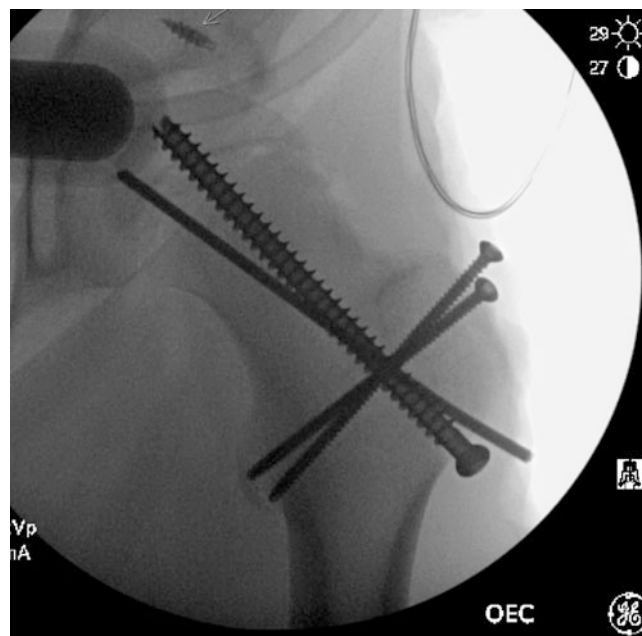


Fig. 5 Intraoperative fluoroscopy showing the final construct with suture anchor in place for posterior, labral avulsion

7 Technical Pearls

A good preoperative neurologic exam is important. There is a 5% rate of sciatic nerve palsy noted with posterior hip dislocations in children but also a 1% incidence noted with the surgical approach (Herrera-Soto and Price 2009; Ganz et al. 2001).

After the capsulotomy is extended, one should carefully evaluate the posterior retinaculum and vessels. Fracture reduction is performed under direct vision, while the hip is dislocated, and provisional fixation allows a controlled reduction of the hip once periosteal repair is performed.

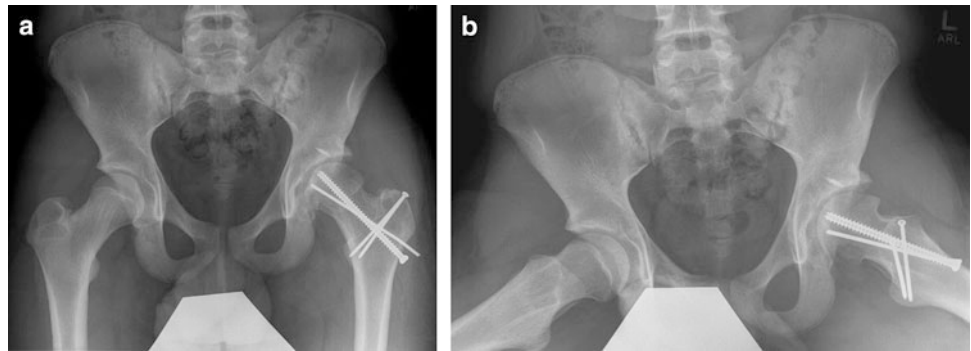
If the retinaculum and periosteal sleeve can be repaired, it should be done with tension-free sutures. Care must also be taken to not overtighten the capsule so as to put undue tension on the retinaculum.

Carefully evaluate the articular cartilage of both the acetabulum and femoral head to document associated injuries. Posterior labral osteochondral avulsions are common with this injury and can be addressed during surgery as well (Blanchard et al. 2016).

8 Outcome Clinical Photos and Radiographs

See Fig. 6a, b.

Fig. 6 AP (a) and lateral (b) radiographs of the left hip 2 years postoperatively showing healed fracture and no evidence of AVN. This patient has returned to normal activities without limitations



9 Avoiding and Managing Problems

With the rate of AVN being significant for these injuries, it is important to follow these patients for at least 2 years (Hughes and Beaty 1994). The treatment of symptomatic AVN depends greatly on the patient's age. Younger patients are likely to develop changes similar to those seen in Legg-Calve-Perthes disease and have a better prognosis than older patients. Adolescents are more likely to be treated similar to adults with possible treatments being anything to prevent femoral head collapse such as containment, core decompression, or vascularized fibular grafts (Herrera-Soto and Price 2009).

10 Cross-References

- [Hip Dislocation](#)
- [Hip Dislocation with Acetabular Fracture](#)

- [Pathologic Proximal Femur Fracture](#)
- [Transphyseal Fracture of Proximal Femur](#)

References and Suggested Readings

- Blanchard C, Kushare I, Boyles A, Mundy A, Beebe AC, Klingele KE (2016) Traumatic, posterior pediatric hip dislocations with associated posterior labrum osteochondral avulsion: recognizing the acetabular "Fleck" Sign. *J Pediatr Orthop* 36(6):602–607
- Ganz R, Gill TJ, Gautier E, Ganz K, Krügel N, Berlemann U (2001) Surgical dislocation of the adult hip: a technique with full access to the femoral head and acetabulum without the risk of avascular necrosis. *J Bone Joint Surg Br* 83-B:1119–1124
- Herrera-Soto JA, Price CT (2009) Traumatic hip dislocations in children and adolescents: pitfalls and complications. *J Am Acad Orthop Surg* 17(1):15–21
- Hughes LO, Beaty JH (1994) Fractures of the head and neck of the femur in children. *J Bone Joint Surg Am* 76:283–292
- Walls JP (1992) Hip fracture-dislocation with transepiphyseal separation: case report and literature review. *Clin Orthop Relat Res* 284:170–175

Femoral Head Fractures

Jenifer Powers and Scott Rosenfeld

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Abstract

Femoral head fractures are a rare fracture in the pediatric and adolescent population. They are usually seen in the setting of high energy trauma, such as motor vehicle collision, and are most frequently associated with a traumatic hip dislocation. They are classified according to the Pipkin classification, based on where the fracture occurs relative to the fovea, and any associated fractures. Pipkin I fractures, those occurring below the fovea, can often be treated conservatively. Pipkin II through IV generally require surgical intervention to correct either articular incongruity or hip instability. While multiple surgical exposures have been previously described depending on the location of the fracture, there is no one preferred technique. Here we will discuss a case of

a Pipkin IV fracture dislocation in a 17-year-old male that was treated via a surgical dislocation approach. This approach allows for a full 360° view of the femoral head as well as access to the acetabulum through a single incision, without compromising the femoral head blood supply.

1 Brief Clinical History

We present the case of a healthy 17-year-old male who was involved in a motor vehicle collision and sustained a traumatic right hip dislocation. This was initially treated with closed reduction at a community emergency department. He was then referred to orthopedic surgery where a CT was obtained which demonstrated a large femoral head fracture and posterior acetabular wall avulsion fracture. He was taken to the operating room where he underwent a surgical

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Fig. 1 Post reduction AP pelvis radiograph demonstrating a right femoral head fracture displaced inferior and medial to the femoral neck

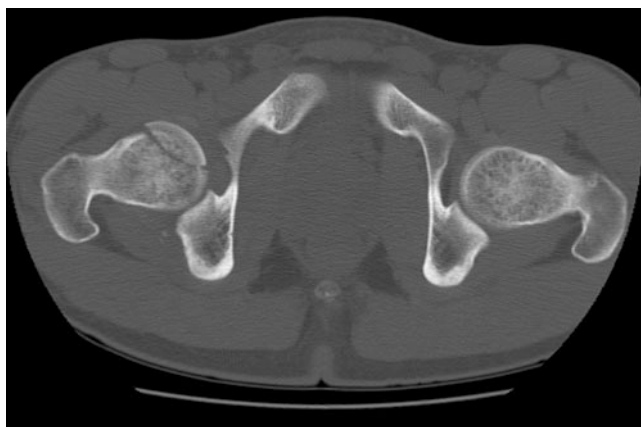


Fig. 2 Axial CT image of the right hip showing the femoral head fracture

hip dislocation with open reduction and internal fixation of the femoral head fracture, osteochondral autograft transplantation of a full thickness femoral head articular cartilage injury, and repair of the posterior wall avulsion fracture. At 1-year post-op, he had a well healed fracture with maintained joint space and no evidence of avascular necrosis or heterotopic ossification. This section will focus only on the approach to and treatment of the femoral head fracture.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4.

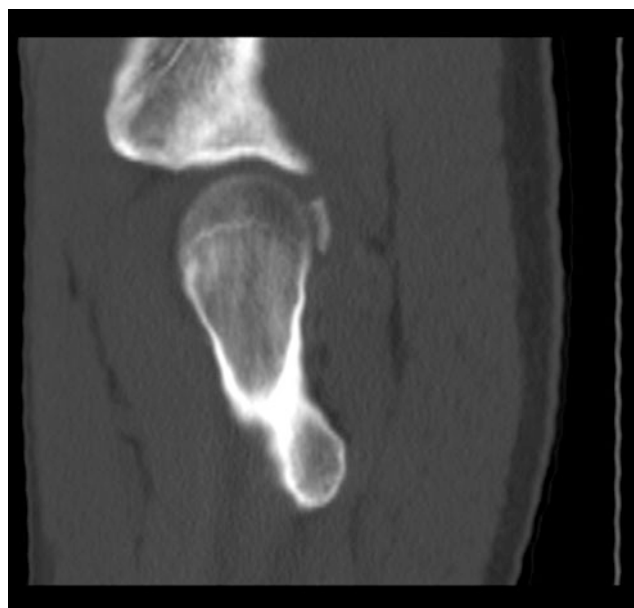


Fig. 3 Sagittal CT image of the right hip showing the small posterior wall fracture

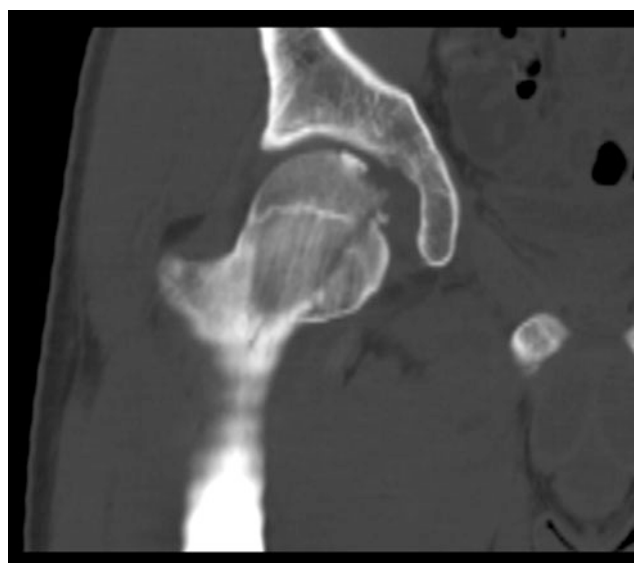


Fig. 4 Coronal CT image of the right hip demonstrating the femoral head fracture inferiorly displaced

3 Preoperative Problem List

1. Right traumatic hip dislocation status post motor vehicle collision
2. Right displaced femoral head fracture
3. Right posterior wall acetabular fracture
4. Right femoral head full thickness chondral defect measuring 1.5 cm in diameter

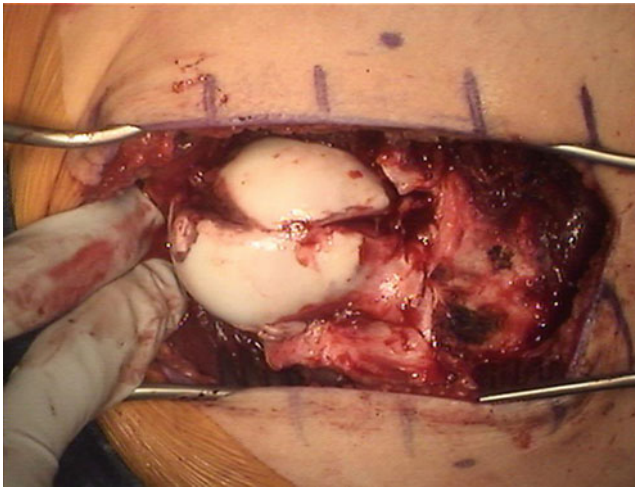


Fig. 5 Clinical photograph demonstrating the femoral head fracture and adjacent chondral defect with exposed subchondral bone

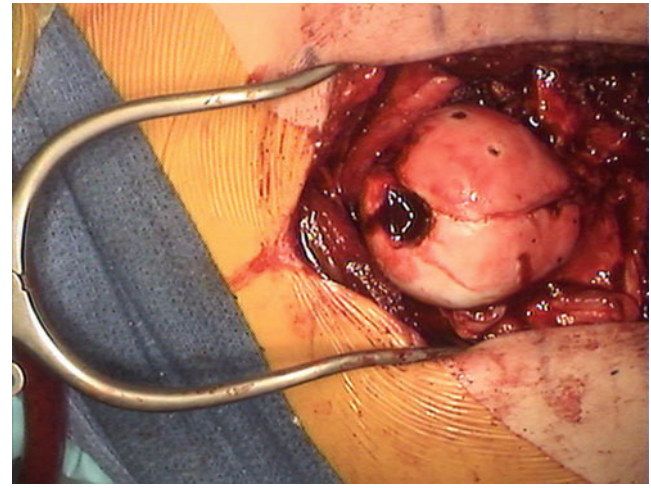


Fig. 6 Clinical photograph after reduction and fixation of the femoral head fracture and debridement of the subchondral bone at the site of the chondral defect

4 Treatment Strategy

Treatment strategy for managing femoral head fractures should be the same, regardless of the surgical approach used. The goals of surgical intervention include anatomic reduction of the articular surface of the femoral head and hip stability through range of motion.

5 Basic Principles

The basic principles of treatment for femoral head fractures are anatomic reduction of the articular surface and hip stability. Traditionally, Pipkin IV fractures were treated through two surgical approaches: one to fix the femoral head and one to address the acetabulum. The surgical dislocation approach provides access to both injuries through a single incision. Our preferred technique is the surgical hip dislocation approach described by Ganz utilizing a lateral approach to the proximal femur. A trochanteric osteotomy is performed where the piriformis tendon remains attached to the stable trochanter fragment and the gluteus medius, minimus, and vastus lateralis are attached to the osteotomized fragment. This interval is safe with regard to the deep branch of the medial circumflex artery (Masse et al. 2015). Anterior dislocation of the hip is then accomplished in a slow and controlled fashion using flexion and external rotation. Once the hip has been dislocated, there is a 360° view of the femoral head, facilitating fracture reduction and implant placement. Care should be taken to not leave screws prominent on the articular surface. Metallic or bioabsorbable screws can be utilized for fixation; however, the authors prefer to use metallic screws so

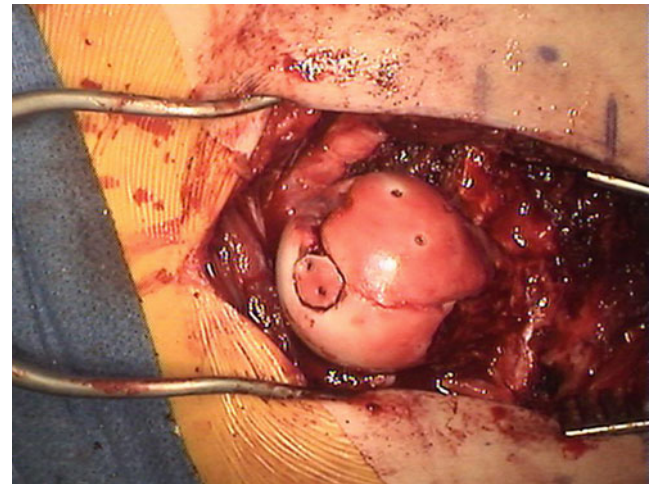


Fig. 7 Clinical photograph after transfer of the osteochondral autograft from the anterior femoral head-neck junction to the site of the chondral defect

that they can be monitored radiographically for loosening and migration.

6 Images During Treatment

See Figs. 5, 6, 7, 8, and 9.

7 Technical Pearls

The patient is positioned in the lateral position on a radiolucent table and stabilized with either a beanbag or pegboard. The extremity is prepped and draped from the toes to the



Fig. 8 Intraoperative AP demonstrating repair reduction and fixation of the femoral head fracture, the osteochondral transfer, and the trochanteric osteotomy



Fig. 9 Intraoperative lateral demonstrating improved articular reduction of the articular surface of the femoral head

costal margin. A hip drape with a sterile bag anterior to the patient is useful to maintain sterility of the extremity after the hip has been dislocated anteriorly. The authors utilize the standard surgical hip dislocation approach as originally described by Ganz et al. (2001). The authors prefer to dissect into the interval between the gluteus maximus and the tensor



Fig. 10 AP Pelvis 1-year post-op demonstrating a healed fracture and maintained joint space

fascia lata muscle so as not to denervate the anterior gluteus maximus with a muscular split. The piriformis tendon should be identified, and the interval between it and the gluteus medius and minimus is dissected to locate the posterior-superior hip capsule. A 2-cm-thick osteotomy of the greater trochanter is made from posterior to anterior. This bone cut is performed lateral to the insertion of the piriformis tendon as it inserts on the medial surface of the greater trochanter. The greater trochanter is retracted anteriorly along with the vastus lateralis, gluteus medius, and gluteus minimus. The piriformis remains attached to the stable trochanter. The dissection of the vastus lateralis off of the lateral and anterior femur should remain extra-periosteal in order to keep dissection superficial to the anterior hip capsule. A T-capsulotomy incision is made, and the hip is flexed and externally rotated to sublunate the hip anteriorly. The ligamentum teres need not be incised as it is typically avulsed from the traumatic dislocation. At this point the femoral head fracture can be evaluated. The authors' preference is to address the femoral head fracture before the acetabular fracture. Addressing the femoral side first allows for easier manipulation of the femoral head and easier placement of fixation. Also, once the femoral side is reduced and congruent in the acetabulum, it is easier to then reduce the acetabular component. The fracture fragment is often attached to the medial retinaculum, and if possible this should be preserved to maintain vascular supply to the fragment. The fragment is then mobilized and advanced to obtain an anatomic reduction of the articular surface. The authors' preference is to fix the fragment with cannulated headless compression screws countersunk below the surface of the articular cartilage. Once the fracture is fixed, the hip should be reduced and taken through range of motion to assess



Fig. 11 Frog leg lateral demonstrating a healed fracture and maintained joint space

for posterior stability. The hip can then be re-dislocated anteriorly and the acetabular fragment can be assessed and fixed if necessary. In this case the acetabular wall fragment was quite small and was repaired with suture anchors.

8 Outcome Clinical Photos and Radiographs

See Figs. 10 and 11.

9 Avoiding and Managing Problems

There are several potential complications to be aware of including avascular necrosis (AVN), heterotopic ossification, hip dislocation, and development of hip osteoarthritis. In cases of isolated traumatic hip dislocations that do not require surgical treatment, there is a 10% risk of AVN (Kellam and Ostrum 2016). This is related to a traumatic injury of the vascular supply to the femoral head. Injury to the femoral head vascular supply can also occur during the surgical hip dislocation approach. Careful dissection cephalad to the piriformis tendon while approaching the hip capsule will allow for preservation of the medial femoral circumflex artery as it enters the hip capsule. Similarly, controlled dislocation with support of the leg by the assistant maintaining the femur parallel to the operating room floor will protect the medial femoral circumflex artery from avulsion once the hip has been dislocated. These technical pearls will help to minimize risk of AVN caused by the surgical approach. According to published literature, the incidence of AVN in hips treated

surgically for femoral head fractures after traumatic dislocation varies from 6% to 20% (Droll et al. 2007). Some of these may have sustained injury to the vascular supply at the time of initial traumatic dislocation and not the time of surgery.

Heterotopic ossification has been reported between 6% and 64% depending on the report and the approach used (Droll et al. 2007). It seems that the anterior approach is at highest risk. Ganz et al. reported a rate of 15.3% when looking at patients only undergoing a surgical dislocation approach. To prevent against heterotopic ossification, we recommend indomethacin prophylaxis for 1 month in the absence of other contraindications.

Injury to the sciatic nerve can occur at the time of injury or due to excessive traction or retractor placement intraoperatively. Postoperative dislocation can occur either anteriorly or posteriorly. As most traumatic hip dislocations are posterior, patients should be placed on posterior hip precautions to prevent re-dislocation. Specifically, they should avoid high angles of hip flexion and adduction. As a result of the surgical anterior capsulotomy and dislocation, patients are also at risk of postoperative anterior dislocation and should avoid external rotation while in hip extension. Patients should be advised to avoid active hip abduction while the trochanter osteotomy heals in order to prevent loss of reduction of the greater trochanter. Despite anatomic reduction, careful soft tissue handling, and appropriate rehabilitation, there is still a high rate of posttraumatic arthrosis. These are often best treated with later total hip arthroplasty.

10 Cross-References

- ▶ [Acetabulum Fracture with Closed Triradiate](#)
- ▶ [Femoral Neck Fractures in Children](#)
- ▶ [Hip Dislocation](#)
- ▶ [Hip Dislocation with Acetabular Fracture](#)

References and Suggested Readings

- Droll KP, Broekhuysen H, O'Brien P (2007) Fractures of the femoral head. *J Am Acad Orthop Surg* 15(12):716–727
- Ganz R, Gill TJ, Gautier E, Ganz K, Krugel N, Berlemann U (2001) Surgical dislocation of the adult hip. A technique with full access to the femoral head and acetabulum without the risk of avascular necrosis. *J Bone Joint Surg Br* 83:1119–1124
- Kellam P, Ostrum RF (2016) Systematic review and meta-analysis of avascular necrosis and post traumatic arthritis after traumatic hip dislocation. *J Orthop Trauma* 30(1):10–16
- Masse A, Aprato A, Alluto C, Favuto M, Ganz R (2015) Surgical hip dislocation is a reliable approach for treatment of femoral head fractures. *Clin Orthop Relat Res* 473:3744–3751
- Pipkin G (1957) Treatment of grade IV fracture-dislocation of the hip. *J Bone Joint Surg Am* 39-A(5):1027–1042

Transphyseal Fracture of Proximal Femur

Megan Mignemi, Jon Schoenecker, and Vince Prusick

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Abstract

Transphyseal fractures of the proximal femur (Delbet 1) are typically the result of high-energy injuries such as motor vehicle accidents or a fall from height and are therefore exceptionally rare, accounting for less than 1% of pediatric fractures. Given the amount of energy involved in these injuries, there are often associated injuries that may require treatment. There is a high risk of avascular necrosis (AVN) (80–100%) associated with this type of fracture, and thus achieving anatomic reduction is important. We present the case of an 11-year-old male who sustained a transphyseal proximal femur fracture and underwent successful closed reduction with percutaneous screw fixation.

1 Brief Clinical History

An 11-year-old male was involved in an ATV-rollover accident and landed directly onto his right hip. He presented with acute right hip pain and inability to bear weight. There was no history of antecedent right hip pain. The right lower extremity was shortened and in an externally rotated and adducted position. He was noted to have a right transphyseal (Delbet 1) femoral neck fracture (Figs. 1 and 2). He had a full trauma workup by the pediatric surgery trauma team. No other injuries noted.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

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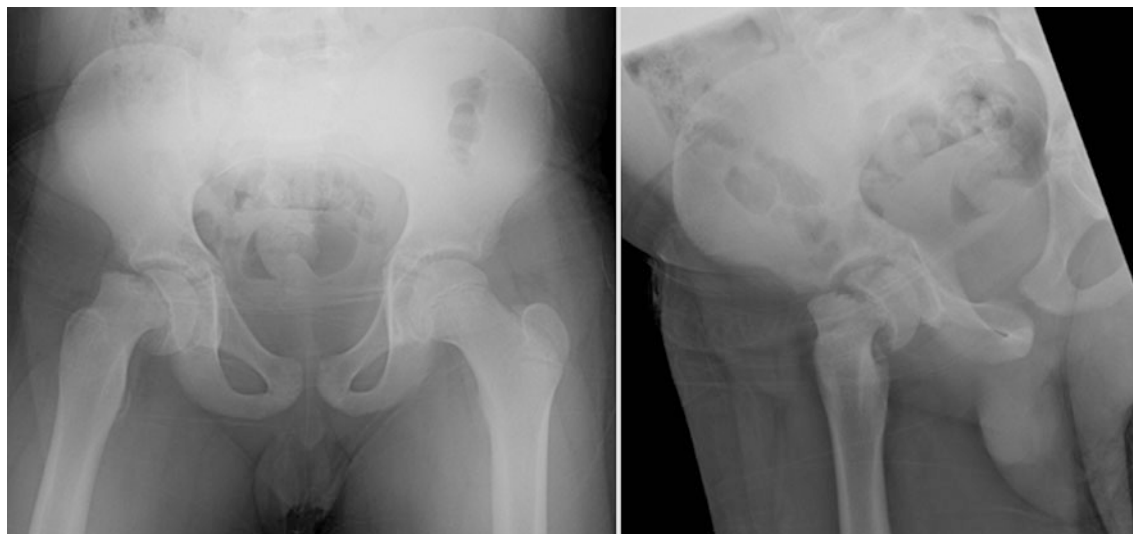


Fig. 1 AP and lateral injury radiograph showing displaced transphyseal proximal femur fracture

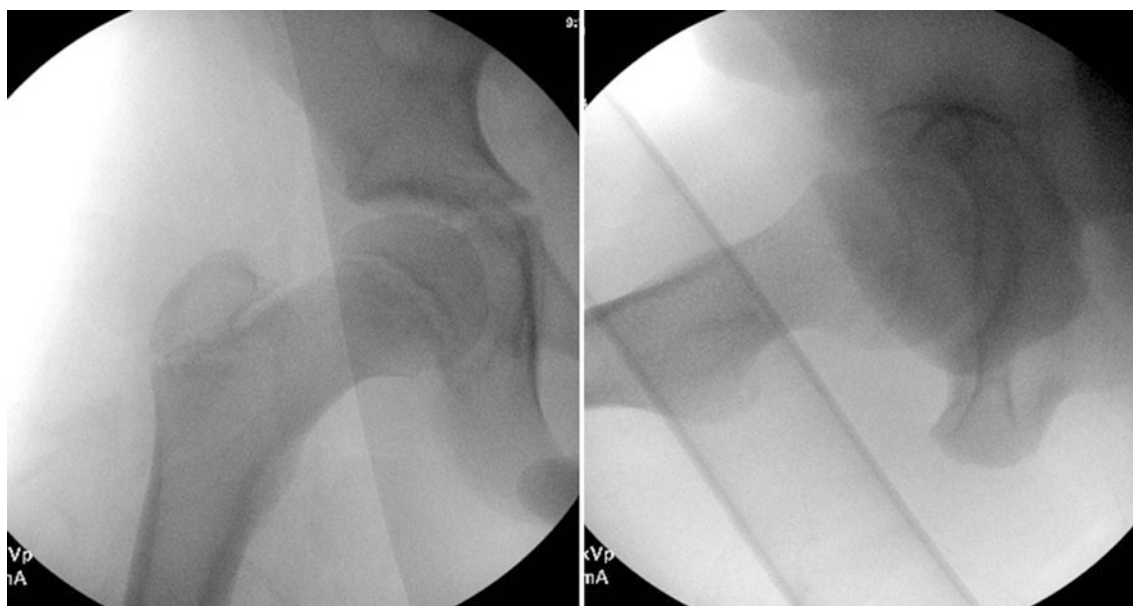


Fig. 2 AP and lateral fluoroscopy showing closed reduction of epiphysis onto metaphysis

3 Preoperative Problem List

- Right transphyseal (Delbet 1) femoral neck fracture

4 Treatment Strategy

Non-operative treatment of transphyseal proximal femur fractures is mostly of historical significance. Cast immobilization alone can have up to a 35% incidence of loss of reduction and varus deformity (Herring 2014). Given the

high rate of AVN associated with this type of fracture, anatomic reduction (closed or open) with rigid internal fixation (Kirschner wires or cannulated screws) is the preferred treatment strategy (Flynn et al. 2015). The patient's age and size will help determine the appropriate implant.

5 Basic Principles

Patient should be placed on a radiolucent table, and fluoroscopic images prior to prepping must be obtained to ensure that adequate visualization of the fracture is possible. Either

a fracture table or flat-top table can be used depending on the surgeon's preference. When prepping the leg, split drapes are used to ensure that the entire hip is exposed in case the fracture is unable to be closed and reduced appropriately and open exposure is needed. Gentle reduction is obtained with traction, followed by sequential abduction, flexion, and then internal rotation. If acceptable closed reduction is confirmed on fluoroscopy, a guide pin for appropriately sized cannulated screw is placed in a center-center position. A second cannulated screw is then placed in a slightly more posterior and inferior position. Fluoroscopy is used to monitor guide pin and screw placement. The lateral view provides a more accurate assessment of the proximity of the screw tip to the joint surface (Figs. 2, 3, and 4). Once all screws are in place, the approach-withdrawal technique is used to ensure there has not been penetration into the joint. Decompression of the joint capsule, either by aspiration or by capsulotomy, should be

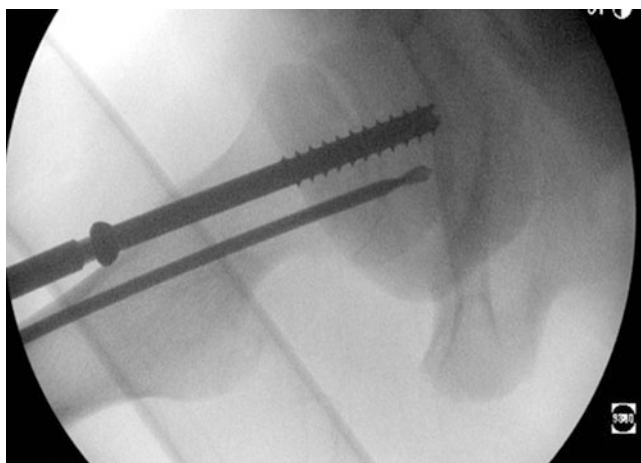


Fig. 3 Lateral fluoroscopy showing central screw in place with second guide pin

performed in order to evacuate the hematoma from within the joint capsule, thereby decreasing intracapsular pressure and the likelihood of AVN.

6 Images During Treatment

See Figs. 2, 3 and 4.

7 Technical Pearls

Either a fracture table or flat-top Jackson table can be used depending on the surgeon's preference. It is vital to ensure that adequate fluoroscopic images can be obtained prior to prepping and draping the patient. The most important aspect of the procedure is to obtain an anatomic reduction. If this cannot be achieved by closed means, then open reduction must be performed. The authors prefer the anterolateral (Watson-Jones) approach to perform open reduction when necessary; however, a Smith-Peterson approach can also be utilized. K-wires can be used for fixation in very young or small children, while cannulated screws are preferred for older children. 6.5 mm or 7.3 mm screws are best for children in the adolescent age group, while smaller screws (4.5 mm) can be used in younger patients. Two screws will provide adequate stability; however, if there is enough room in the femoral neck, three screws can be used in an inverted triangle configuration. Cast immobilization postoperatively is generally not necessary if screw fixation is performed. In younger children, in whom K-wires are used, or in children who cannot follow weight-bearing precautions postoperatively, consider the use of a spica cast.

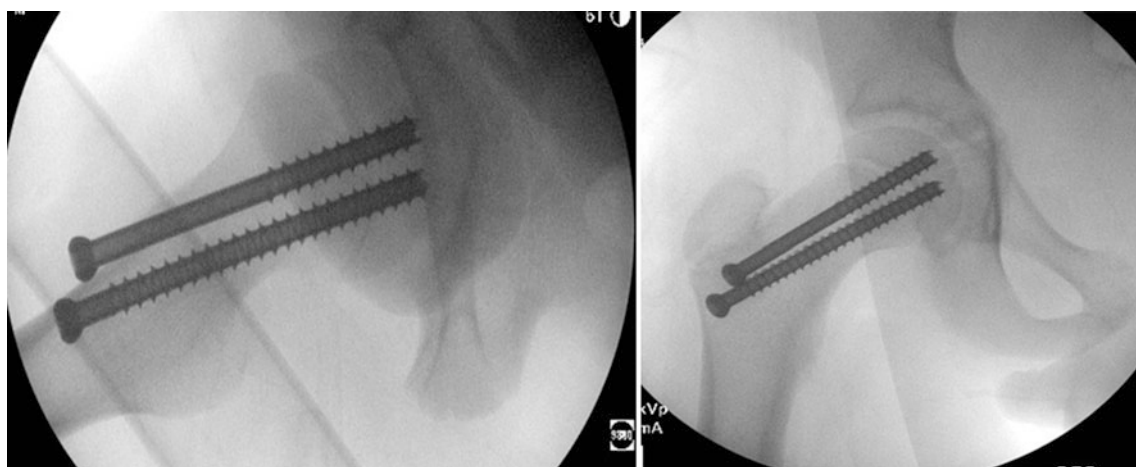


Fig. 4 AP and lateral fluoroscopy showing final screw placement and well-reduced epiphysis

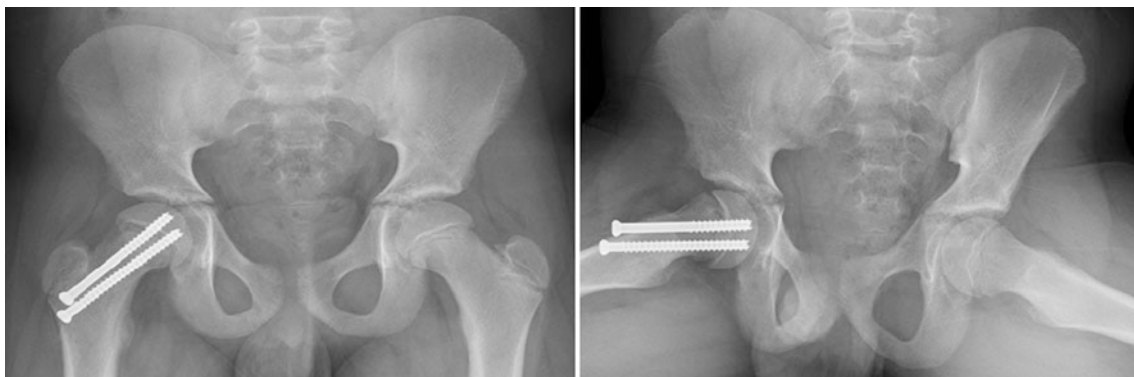


Fig. 5 AP and lateral 1 month postoperative

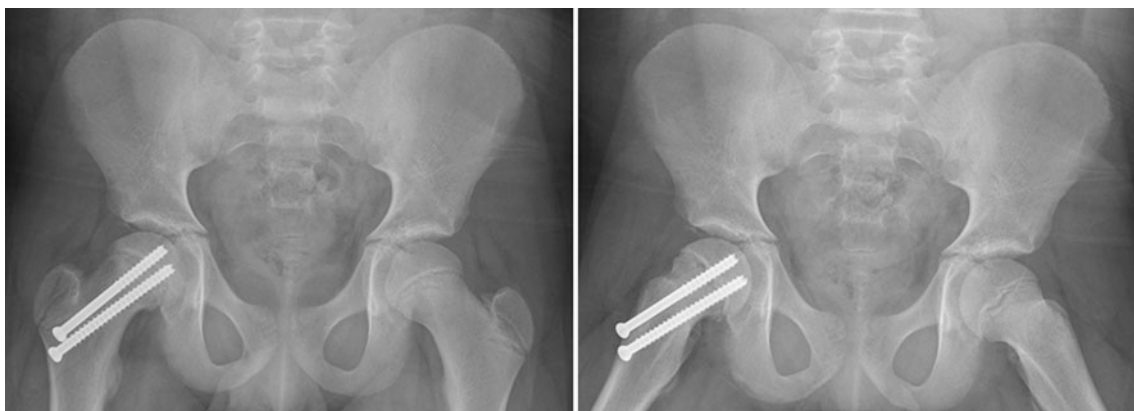


Fig. 6 AP and lateral 5 months postoperative

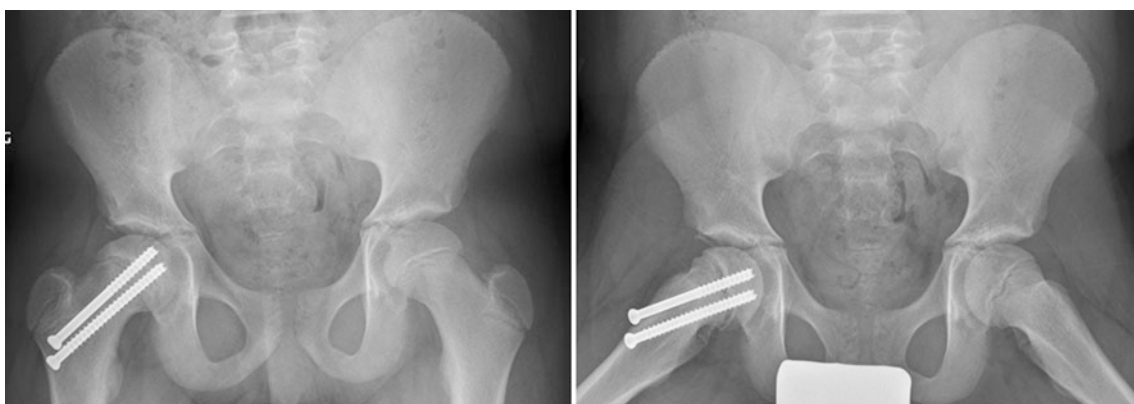


Fig. 7 AP and lateral 7 months postoperative

8 Outcome Clinical Photos and Radiographs

See Figs. 5, 6, and 7.

9 Avoiding and Managing Problems

The most common complication associated with transphyseal fractures of the proximal femur is AVN of the femoral head. The physis creates a unique situation in children, as compared

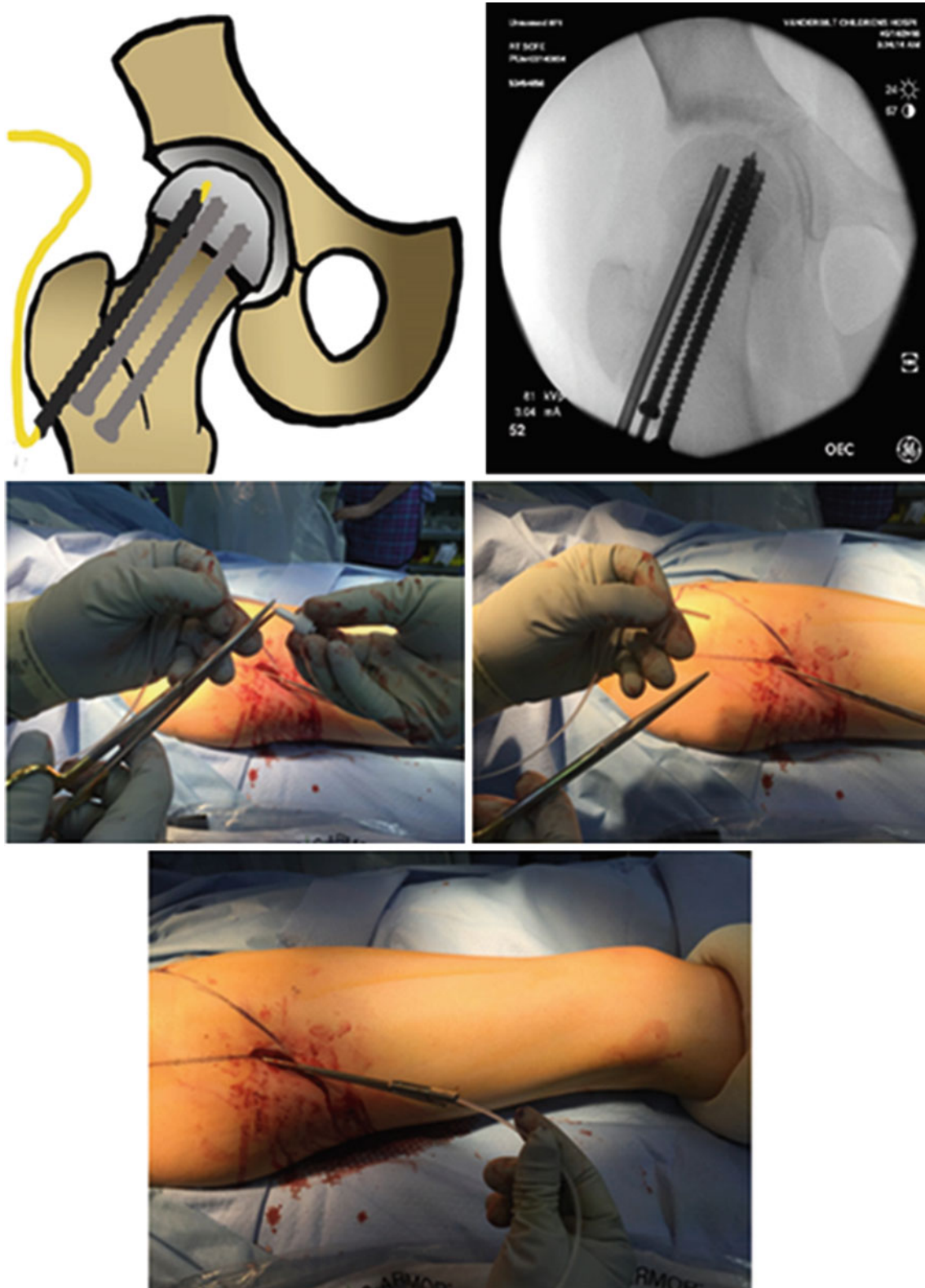


Fig. 8 These images depict the setup for arterial line monitoring of epiphyseal perfusion utilized by the authors

to adults, where the metaphyseal and epiphyseal blood supplies are segregated. Therefore, in the setting of injury to the epiphyseal vessels, the epiphysis cannot be revascularized from the metaphysis. Given this feature, the incidence of AVN for this type of fracture is between 80% and 100% and is often devastating. Historically, it was thought that urgent/emergent treatment of transphyseal femoral neck fractures was necessary to avoid AVN. However, recent studies have demonstrated that compromise of the lateral epiphyseal blood supply is more likely a result of the damage caused by the trauma itself and not the timing of operative fixation. Achieving an anatomic reduction is important to minimize the risk of AVN. If reduction cannot be achieved by closed means, then an open approach must be done to reduce the fracture. Screw placement should be (1) proximal to the lesser trochanter to avoid creating a stress riser and subsequent fracture and (2) lateral to the intertrochanteric line to minimize the risk of screw cut out (Mencio and Swiontkowski 2014).

Close follow-up is necessary to monitor for the development of AVN in these patients. AVN is typically first noted on plain radiographs several months after the original injury. Unfortunately, by this time most kids are advanced to full weight-bearing, which can lead to early collapse of the

femoral head. In order to minimize the risk of AVN occurring, it is ideal to determine the status of the epiphyseal blood supply during the operation. The authors utilize an intravenous tubing threaded up a cannula into the epiphysis attached to an arterial line monitor to assess epiphyseal blood flow once the fracture has been reduced and stabilized. While this method is not yet validated, they have had success with it (Fig. 8). Pinhole bone scan is used in conjunction with plain radiographs to assess the blood flow to the femoral epiphysis postoperatively. The bone scan can also be used to assess blood flow across the fracture site (a requisite for fracture union). The authors restrict weight-bearing until blood flow to the femoral epiphysis and fracture healing is confirmed on bone scan.

References and Suggested Reading

- Flynn J, Skaggs D, Waters P (2015) Rockwood and Wilkins' fractures in children. Wolters Kluwer, Philadelphia
- Herring J (2014) Tachdjian's pediatric orthopaedics. Elsevier, Philadelphia
- Mencio GA, Swiontkowski MF (2014) Green's skeletal trauma in children. Elsevier, Philadelphia

Femoral Neck Fractures in Children

Michael Fisher, Patrick Riley Jr., and Kenneth Bono

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Abstract

Femoral neck fractures in the pediatric population are uncommon injuries, making up less than 1% of all pediatric fractures. The mechanism of injury is typically high-energy trauma or a fall from height. As with all high-energy traumas, it is common to find cranial, visceral, or other serious injuries. The presence of concomitant trauma can make treatment of these injuries challenging. Early reduction and stable internal fixation are critical to minimize complications, which are common. The most dreaded and, unfortunately, most common complication is avascular necrosis of the femoral head.

The following case typifies a pediatric femoral neck fracture and illustrates surgical management of the injury. The patient sustained a Delbet type III basicervical femoral neck fracture after being involved in a high-energy

automobile accident. This case demonstrates a method of surgical management and shows the follow up including addressing possible complications. We present the clinical decision-making and considerations in approaching treatment of this type injury.

1 Brief Clinical History

A 13-year-old male was an unrestrained passenger in an automobile travelling approximately 50 miles per hour that collided with a stalled car in an intersection. The patient was ejected from the back seat and the right half of his body struck the front console. The patient had a transient loss of consciousness, and was transported to a local hospital by ambulance in stable condition. Radiographs from the outside facility demonstrated a displaced right femoral neck fracture. After evaluation for other injuries at the outside facility, he was transferred to our hospital for management of the femoral neck fracture. He had no neurovascular compromise in the right lower extremity and sustained no other major injuries.

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2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

1. Displaced right basicervical femoral neck fracture

4 Treatment Strategy

Initial management of this injury, as it presents to the trauma bay, is systematic employment of Advanced Trauma Life Support principles. The patient's hemodynamic status must be assessed and stabilized. It is common for the patient to present with head and visceral injuries. Careful evaluation of all critical body systems will help to avoid missed untreated injuries. When the patient is stable, definitive orthopedic management of the femoral neck can occur. In this case, the patient had a full evaluation and workup by the trauma service, which did not reveal any additional injuries. The patient was cleared for surgery. The key principles to treatment of femoral neck fractures are anatomic reduction of the fracture and stable fixation of the fracture fragments (Morsy 2001; Riccio et al. 2013). Urgent treatment (less than 24 h) and capsular decompression may influence the rate of postoperative avascular necrosis (Shrader et al. 2006; Yeranorian et al. 2013). However, Riley et al. showed no correlation between the time to reduction nor capsular decompression in the development of osteonecrosis of the femoral head (Riley et al. 2015). Younger age at injury has been shown

in several studies to be protective in the development of avascular necrosis (Riley et al. 2015; Moon and Mehlman 2006).

The patient was brought to the operating room emergently, approximately six hours after injury. In the operating room, the patient was placed supine on a fracture table. The right foot was secured in the fracture table boot and closed reduction with fluoroscopy was utilized. Fracture table was used to pull longitudinal traction, internally rotate, and slightly abduct the right leg. After the reduction, the fracture appeared well-aligned, but comminution was noted at the inferior femoral neck near the calcar. Fluoroscopy and a Steinmann pin were used to mark starting points outside the skin and an incision was made on the lateral thigh. Subcutaneous tissue and iliotibial band were incised and starting point for the 6.5 mm cannulated screw guide wires was identified using c-arm. Three guide wires were placed, using fluoroscopy, in an inverted triangle pattern. Care was taken to stop short of the physis. The superior anterior cannulated screw was placed first to provide some compression on the noncomminuted side of the fracture. The inferior screw was placed last with care taken not to compress through the comminution and increase varus malalignment of the fracture. After all screws were placed, the c-arm was used to confirm satisfactory reduction and fixation. A Cobb elevator was used to perform a capsular decompression by carefully sliding up the anterior cortex of the femoral neck and gently elevating the joint capsule off the anterior femoral neck. Final x-rays showed a well-aligned femoral neck fracture. The wound was irrigated, closed, and dressed. The patient was taken to the recovery room and admitted for postoperative care and observation for occult injuries.



Fig. 1 AP pelvis radiograph that demonstrates a basicervical femoral neck fracture of the right femur

5 Basic Principles

Children subjected to high-energy trauma should undergo initial evaluation and stabilization of life-threatening injuries. Femoral neck fractures should then be an urgent priority of treatment following stabilization. Complications are common in this infrequent injury (Riccio et al. 2013). The most dreaded complication and, unfortunately, most common is avascular necrosis of the femoral head (Boardman et al. 2009). Anatomic, or near anatomic, reduction, when able, and stable fixation, are two important principles guiding treatment in this case. Anatomic reduction and stable fixation have been shown to decrease risk of avascular necrosis, fracture malunion, and nonunion (Shrader et al. 2006). Time to fracture reduction is also a factor that may contribute to risk of avascular necrosis. Some studies have

Fig. 2 AP radiograph of the right proximal femur demonstrating basicervical fracture of the femoral neck and no noted femoral shaft fracture

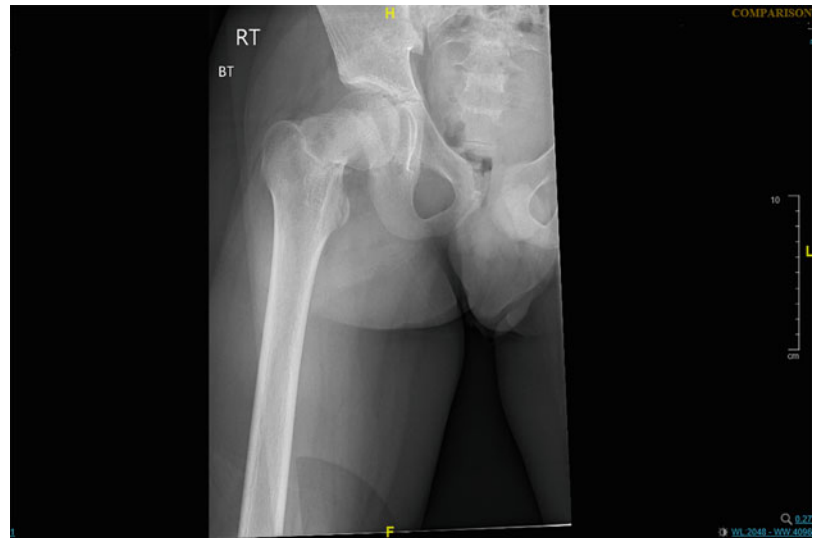
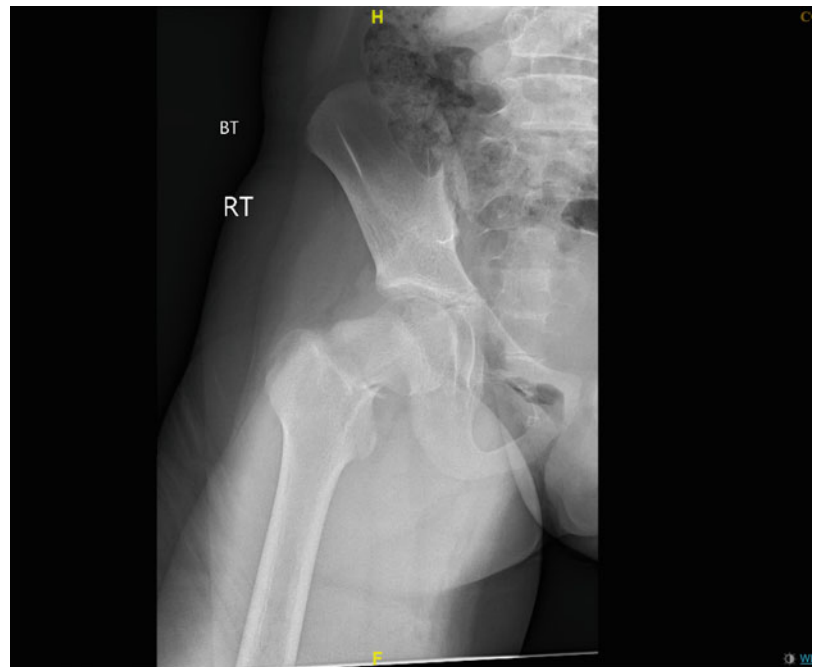


Fig. 3 Coned down radiograph of the right hip. Note the inferior femoral neck comminution with displacement and angulation of the fracture



shown that aggressive early intervention (less than 24 h) reduces the risk of avascular necrosis (Yeranosian et al. 2013). Capsular decompression has been advocated to potentially reduce risk of avascular necrosis (Boardman et al. 2009), but has been disputed in other studies (Riley et al. 2015).

A clear explanation of potential complications with patient and parents can help establish expectations. The Delbet classification system describes fracture pattern by anatomic location. This system can aid in predicting risk of avascular necrosis (Riccio et al. 2013). The literature has identified three surgeon independent variables that

increase risk of avascular necrosis. Age of patient at time of injury, magnitude of displacement of the fracture, and anatomic location of the fracture are all variables that the surgeon has no control over. Younger age has been shown to have lower risk of avascular necrosis. Greater magnitude of displacement increases risk of avascular necrosis. Delbet type I fractures have the highest risk of avascular necrosis and this risk decreases stepwise with fracture type (Yeranosian et al. 2013). There is still much debate regarding capsular decompression, open versus closed reduction, and timing to surgical intervention.

6 Images During Treatment

See Figs. 4 and 5.

7 Technical Pearls

Use of the fracture table may be helpful in certain fracture patterns. The fracture table allows for indirect reduction of the fracture and maintenance of the reduction without

multiple assistants. In the very young patient, fracture table may not be appropriate based on patient size. Very young patients may be treated with hip spica casting if alignment is satisfactory. There is a limited ability to perform open reduction using a fracture table. Selecting more minimally displaced fractures in older patients for use with fracture table will aid in surgical planning.

Capsulotomy for decompression can be performed in a number of ways. Needle decompression with aspiration of the deep capsular hematoma can be done early following

Fig. 4 AP radiograph of the right hip demonstrating satisfactory reduction of the femoral neck fracture with three cannulated partially threaded 6.5 mm cancellous screws

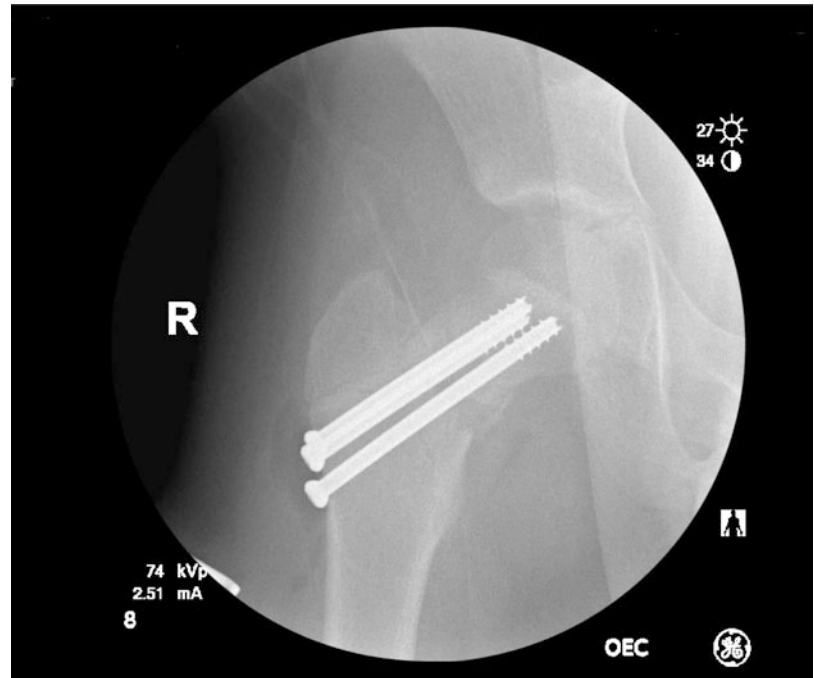
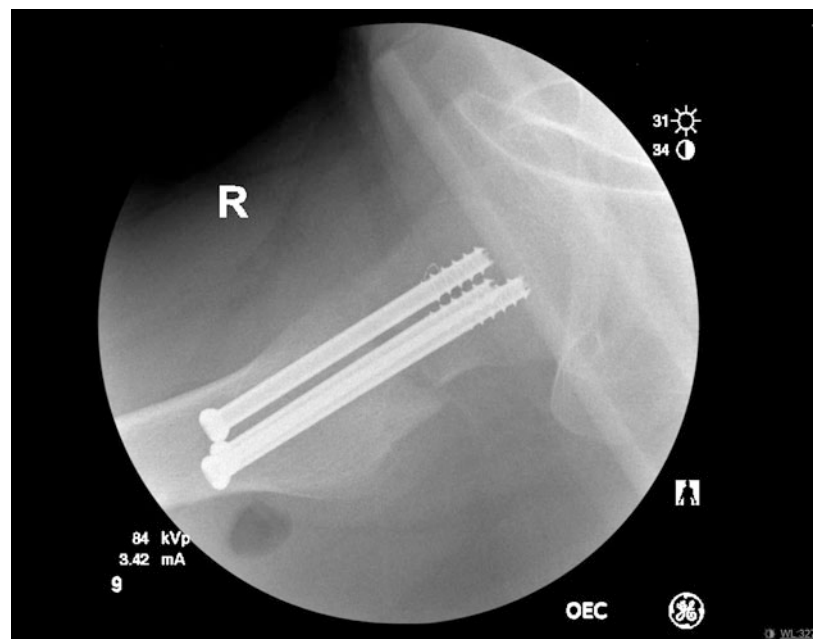


Fig. 5 Lateral radiograph of the right hip demonstrating satisfactory alignment of the fracture with screws outside proximal femoral physis



injury. Coagulation of hematoma with time can limit the ability to adequately decompress the hip capsule with needle alone. Open approaches to the hip with a variety of capsular incisions are possible (Riccio et al. 2013). In this case, the lateral aspect of the proximal femur was exposed and the Cobb elevator was passed along the anterior aspect of the femoral neck to perform capsulotomy. It is important to fixate the fracture, in this case, prior to capsular decompression because of potential loss of reduction while manipulating the femoral neck with the Cobb. Applying compression to the fracture allows for improved bone healing. Compression can minimize risk of malunion and nonunion. Typically, the use of the inferior screw to provide compression along the inferior neck or calcar is desirable. In the above case, the inferior femoral neck was comminuted and compression was achieved with the superior screws. Care was taken with the inferior screw not to pull the femoral head into varus, altering hip mechanics.

If adequate fixation can be achieved without violating the proximal femoral physis, it should be considered. The proximal femoral physis contributes to only 15% of lower extremity length, but premature physeal closure can result in functional alterations. If stable fixation cannot be achieved short of the physis, it should be crossed to provide appropriate stability (Boardman et al. 2009). Accurate screw measurement should be an area of focus. This will prevent violation of the physis but also limit complaints of postoperative hardware prominence. Removal of hardware here is controversial and is surgeon-dependent. Closed reduction maneuvers should be gentle and limited in number of attempts. This prevents excessive trauma to the already tenuous vascular supply to the femoral head. A low threshold for open reduction should exist in difficult cases. A standard Smith-Petersen anterior approach should be utilized when satisfactory reduction cannot be achieved or maintained with closed means.

8 Outcome Clinical Photos and Radiographs

See Figs. 6, 7, 8, 9, and 10.

9 Avoiding and Managing Problems

Complications historically are very common with femoral neck fractures in children (Morsy 2001). Improvements in treatment have reduced the rates of complication but the incidence is still high. Urgent (<12 h) anatomic reduction should be the guiding principle in treatment of these injuries (Shrader et al. 2006). Although, most cases of osteonecrosis of the femoral head occur within 6–7 months, these fractures



Fig. 6 AP radiograph of the right hip at 6 months postop demonstrating healing fracture of the femoral neck with suggestion of premature physeal closure

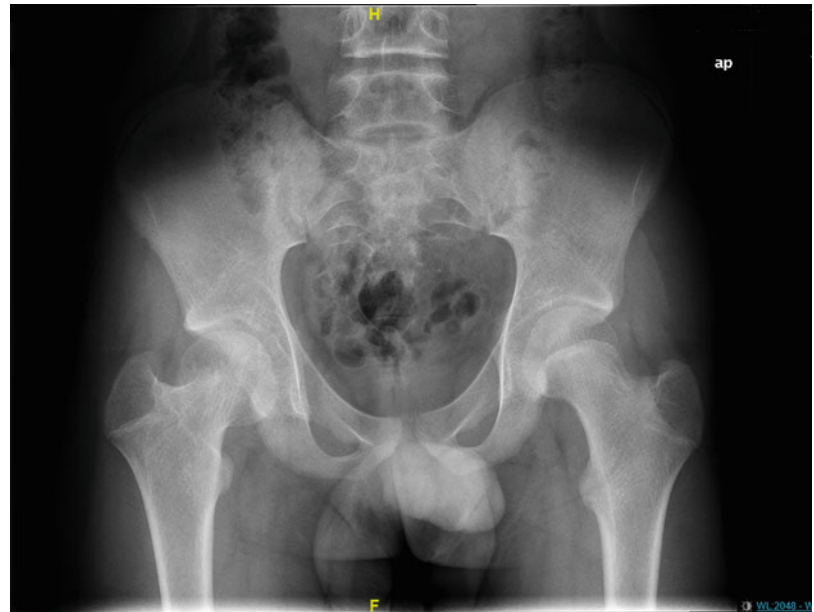


Fig. 7 Lateral radiograph right hip at 6 months postop demonstrating healing fracture of the femoral neck

Fig. 8 AP radiograph of right hip after removal of hardware at 1 year following injury



Fig. 9 AP radiograph of the pelvis at 2 years follow up demonstrating no evidence for head collapse secondary to avascular necrosis, but notable right-sided coxa magna, breva, and vara.



should be followed for a minimum of one year after fixation before avascular necrosis of the femoral head can be ruled out. In this case, at 3 years follow up, the patient continued to be pain free, without any symptoms attributed to avascular necrosis, although the minimal coxa magna noted on xray suggests he likely did experience some small degree of AVN which would not be expected to alter his treatment. He was also noted to have premature physeal closure with growth arrest of the proximal femur, causing mild leg length

discrepancy of 8 mm. This occurred despite physeal sparing internal fixation. The shortening of the femoral neck is evidence of this complication. The patient has a mild leg length discrepancy of 8 mm at skeletal maturity, which is asymptomatic, and would not be expected to require further treatment. More significant leg length discrepancies at may require additional treatment such as shoe lifts, contralateral epiphysiodesis, or lengthening procedures, depending on the degree of discrepancy. This patient did develop coxa vara as well which can be



Fig. 10 Full-length radiograph of bilateral lower extremities taken 3 years after injury demonstrates a 8 mm leg length discrepancy

attributed to the inferior femoral neck comminution allowing for varus collapse or from physeal closure. Significant symptomatic coxa vara can be addressed with valgus osteotomy. The patient did have some abductor weakness likely related to relative greater trochanteric overgrowth. He was treated with therapy regimen directed at strengthening the abductors. If this continues to be symptomatic, a trochanteric osteotomy with advancement is an option to re-tension the abductor musculature.

When placing cannulated screws, they should be placed proximal to the lesser trochanter to avoid causing a sub-trochanteric stress riser. If patients wish to participate in contact sports, hardware removal should be considered to prevent future fracture. Activity restriction is critical after hardware removal to protect the screw tracts while they heal and prevent re-fracture. The selection of what screw size one should use to fix these fractures is dependent on patient age and size. One should select a screw size that allows for maximal strength, while still allowing multiple screws to be placed. This is important in a narrow femoral neck that does

not permit three screws in the optimal inverted triangle configuration. All guide wires should be placed prior to drilling or placing screws. This prevents rotation of the proximal fracture fragment that could potentially devascularize the femoral head.

It has been suggested that an early post-operative bone scan may be an effective tool in establishing an early diagnosis of AVN of the femoral head so that treatment before x-rays. This may prove beneficial as treatment may be instituted prior to femoral head collapse (Parikh et al. 2017).

10 Cross-References

- [Femoral Head Fractures](#)
- [Hip Dislocation](#)
- [Transphyseal Fracture of Proximal Femur](#)

References

- Boardman MJ, Herman MJ, Buck B, Pizzutillo PD (2009) Hip fractures in children. *J Am Acad Orthop Surg* 17:162–173
- Delbet P, Citedin Colonna PC (1928) Fracture of the neck of the femur in childhood: a report of six cases. *Ann Surg* 88:902
- Moon ES, Mehlman CT (2006) Risk factors for avascular necrosis after femoral neck fractures in children: 25 Cincinnati cases and meta-analysis of 360 cases. *J Orthop Trauma* 20(5):323–329
- Morsy HA (2001) Complications of fracture of the neck of the femur in children. A long-term follow-up study. *Injury* 32:45–51
- Parikh, AK, Washington ER 4th, Bobbey AJ, Spottswood SE (2017) Evaluation of femoral head viability via bone scintigraphy in the postoperative pediatric patient. *Pediatr Radiol* [Epub ahead of print].
- Riccio AI, Wilson PL, Wimberly RL (2013) Lower extremity injuries. In: Herring JA (ed) *Tachdjian's pediatric Orthopaedics: from the Texas Scottish rite hospital for children*, 5th edn. Saunders, Philadelphia, Pennsylvania, pp 1383–1398
- Riley PM Jr, Morscher MA, Gothard MD, Riley PM Sr (2015) Earlier time to reduction did not reduce rates of femoral head osteonecrosis in pediatric hip fractures. *J Orthop Trauma* 29:231–238
- Shrader MW, Jacofsky DJ, Stans AA et al (2006) Femoral neck fractures in pediatric patients 30 years experience at a level 1 trauma center. *Clin Orthop Relat Res* 454:169–173
- Yeranosian M, Horneff JG, Baldwin K, Hosalkar HS (2013) Factors affecting the outcome of fractures of the femoral neck in children and adolescents. *Bone Joint J* 95-B:135–141

Suggested Reading

- Riccio AI, Wilson PL, Wimberly RL. (2013) Lower extremity injuries. In: Herring JA (ed) *Tachdjian's pediatric Orthopaedics: from the Texas Scottish rite hospital for children*, 5th edn. Saunders, Philadelphia, Pennsylvania, pp 1383–1398
- Sink EL, Kim YJ (2014) Fractures and traumatic dislocations of the hip in children. In: Flynn JM (ed) *Rockwood and Wilkin's fractures in children*, 8th edn. Lippincott Williams & Wilkins, Philadelphia, Pennsylvania, pp 953–986

Pediatric Intertrochanteric Proximal Femur Fracture

Walter H. Truong and Lisa Soumekh

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Abstract

Hip fractures, a common injury among the elderly, are rare for children and are associated with a higher risk for complications. A low incidence rate combined with the risk for serious complications makes it important to understand and examine the rare cases that arise. Here, we discuss the case of a previously healthy 12-year-old who was brought to the emergency room following a motor vehicle crash. He was initially seen at an outside, rural facility and then transferred to our level 1 trauma center. The patient complained of right hip pain and was subsequently diagnosed with a displaced, right three-part intertrochanteric proximal femur fracture. He was treated by open reduction and internal fixation on the same day he

was admitted. The fracture was stabilized with a 5-mm proximal femoral locking plate without fixation into the fractured lesser trochanter. The patient began full weight-bearing 6 weeks postoperatively and was allowed back to straight ahead running at 4 months. Type IV fractures usually have good outcomes; however, we plan to follow his growth to determine if and when the locking plate is removed.

1 Brief Clinical History

A previously healthy 12 year old presented to the emergency department following a motor vehicle crash. The patient was a restrained passenger sitting in the rear passenger seat of the car. The patient presented with right hip pain and denied having pain in the rest of his body. The patient also denied hitting his head, but he admitted that he

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lost consciousness for “a few seconds” during the accident. He had a full trauma evaluation, and subsequently, he was diagnosed with a displaced, right intertrochanteric proximal femur fracture. The patient had no past surgeries, no known allergies, was not taking any medications, and had no family history of easily broken bones or early joint replacement surgery.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.



Fig. 1 AP pelvis X-ray during trauma evaluation

3 Preoperative Problem List

1. Right displaced intertrochanteric proximal femur fracture
2. Loss of consciousness

4 Treatment Strategy

Following a full trauma evaluation including a pelvis X-ray and a head/c-spine/chest/abdomen/pelvis CT, the patient's only diagnosed injury was a right intertrochanteric proximal femur fracture. Intracranial injury was ruled out. The proximal fragment of the hip fracture was shortened and displaced posteriorly. We decided to treat the fracture with open reduction and internal fixation on the same day he was admitted. For children who suffered from femoral neck fractures, early stabilization can have a positive impact on long-term outcomes. Since the lesser trochanter was fractured, this represented a three-part intertrochanteric fracture. Concern was whether that would need separate stabilization or was it still in continuity and creating a flexion moment on the proximal femur. Patient was positioned supine on the fracture table. Prior to draping, fluoroscopy was used to ensure fracture was out to length and reducible with gentle traction. Shower curtain drape was used, and a standard lateral approach was made to the proximal femur. Posterior 2/3 of the vastus lateralis attachment to the ridge was already disrupted by the fracture; thus, we released the anterior portion to allow visualization of the fracture site. Proximal fragment was flexed and externally rotated, while the distal fragment was pos-

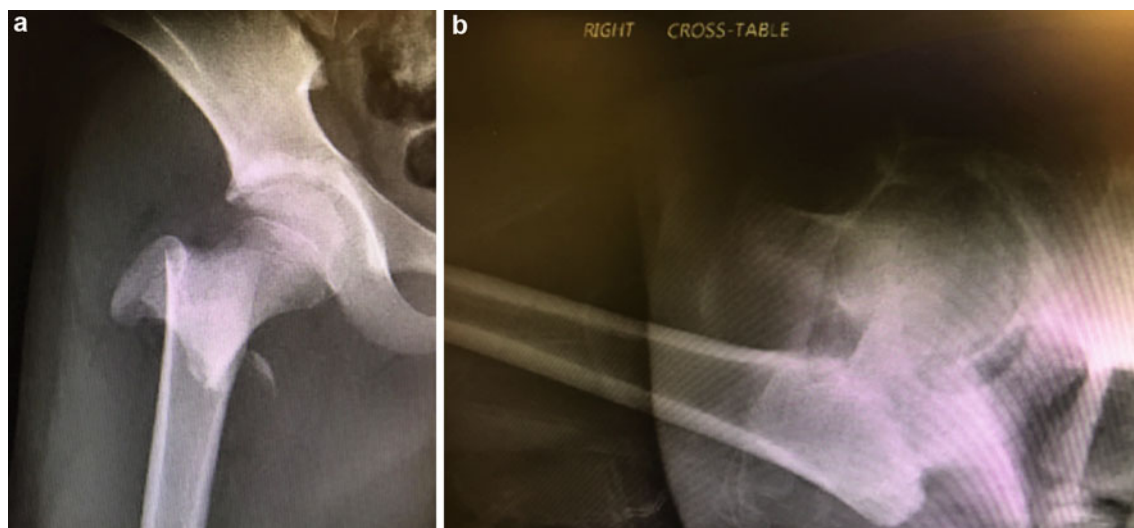


Fig. 2 (a) Preoperative AP right hip, (b) Preoperative X-table lateral right hip

terior and shortened. This confirmed that the lesser trochanter was still exerting force on the proximal piece. Therefore, we reduced the distal fragment to the femur and left the lesser trochanter alone. Once the fracture was reduced with increased traction and external rotation, we passed a guide pin for the 5-mm locking plate and placed it at 130° , which matched the neck shaft of the other side. This guide pin actually passed from the distal fragment into the femoral neck. Since there was still some instability at the fracture site, we placed a second Steinmann pin for rotational stability. We drilled and placed a non-locking screw through the plate to reduce the fracture, and although there was a gap on the X-ray, representing a small posterior gap, the anterior cortex was visualized and in contact. Two proximal locking screws were then placed, and the non-locking screw was replaced with a locking screw. Shaft screws were placed; then the joint capsule was opened to ensure there was decompression of any intra-articular hematoma; no blood was present.

5 Basic Principles

Similar to adult hip fractures, early stabilization and mobilization has its advantages. For difficult pediatric hip fractures, especially those within the femoral neck, locking plates have become an effective and safe way to stabilize the fracture (Hedequist et al. 2008). These fixed angle devices provide added stability, avoiding the need for previously advocated spica casting (Swiontkowski and Winkler 1986) and mitigating the risk of complications such as malunion and coxa vara (Davison and Weinstein 1992).

6 Images During Treatment

See Fig. 3.

7 Technical Pearls

Use a fracture table; it makes positioning, imaging, and reduction easier. Rotate the distal fragment to match the proximal fragment, and stabilize temporarily with guide pin and Steinmann pins. That will allow you to rotate the proximal fragment into a better position for placing the plate. The lesser trochanter may be fractured but can be stable and in continuity with the proximal fragment, requiring no further



Fig. 3 Immediate postoperative AP right hip

fixation. Use a non-locking screw to reduce the fracture and the plate to the bone, prior to placing locking screws.

8 Outcome Clinical Photos and Radiographs

See Fig. 4.

9 Avoiding and Managing Problems

When comparing the different types of pediatric hip fractures, Type IV fractures typically have the best outcomes. Avascular necrosis and physeal closure are rare complications (Gamble et al. 1991). Coxa vara is more common and is seen in about 10–30% of cases (Forlin et al. 1992). Careful management and observation can prevent coxa vara; however, if it arises, it can be treated with a subtrochanteric or intertrochanteric valgus osteotomy. An additional area of concern is the locking plate that was used to fix the fracture. The patient is already 12 years old and so; his predicted growth will determine if and when the plate is removed. If there is a concern that the locking screws will enter the subtrochanteric area, we will consider removing them.

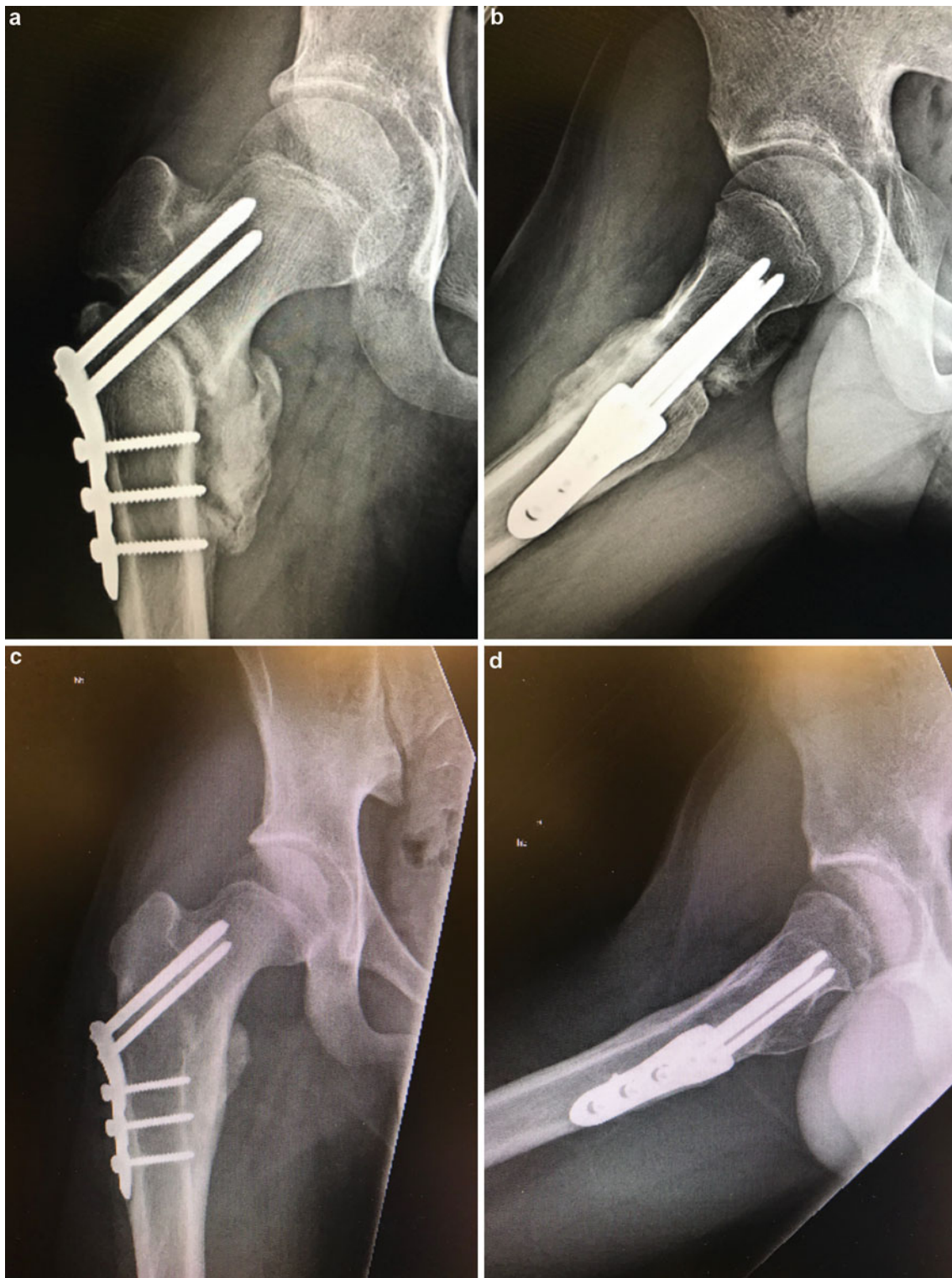


Fig. 4 (a and b) Four and a half months postoperative AP and lateral XR. No pain, mild Trendelenburg limp, full range of motion. 5/5 hip flexion strength, 4/5 hip abduction strength. Concern for incomplete

union on AP but has bridging callus distal-medial and anteriorly on lateral view. (c and d) Ap and lateral XR 2 years postoperative. Significant remodelling. No limp.

10 Cross-References

- [Femoral Head Fractures](#)
- [Femoral Neck Fractures in Children](#)
- [Pathologic Proximal Femur Fracture](#)

References and Suggested Reading

Davison BL, Weinstein S (1992) Hip fractures in children: a long term follow up study. *J Pediatr Orthop* 12:355–358

Forlin E, Guille JT, Kumar SJ, Rhee KJ (1992) Complications associated with fracture of the neck of the femur in children. *J Pediatr Orthop* 12(4):503–509

Gamble JG, Lettice J, Smith JT, Rinsky LA (1991) Transverse cervicopertrochanteric hip fracture. *J Pediatr Orthop* 11(6):779–782

Hedequist D, Bishop J, Hresko T (2008) Locking plate fixation for pediatric femur fractures. *J Pediatr Orthop* 28(1):6–9

Swiontkowski MF, Winquist RA (1986) Displaced hip fractures in children and adolescents. *J Trauma* 26:384–388

Pathologic Proximal Femur Fracture

Kenneth Bono

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Abstract

Pathologic fractures of the proximal femur can be particularly difficult to treat. They require the surgeon to prioritize the need to determine a definitive underlying diagnosis of the pathologic lesion when appropriate, and determine whether conservative or operative treatment may be required based on the fracture stability, and potential risks of malunion and avascular necrosis when treating femoral neck fractures in particular. When there is concern for a potential malignant pathologic lesion, the priority should be to establish a diagnosis by biopsy, and treat the fracture conservatively initially, as the underlying diagnosis may alter potential treatment considerations. Once a diagnosis is known by biopsy, or a benign lesion is essentially diagnosed by radiographs alone, definitive treatment can proceed.

1 Brief Clinical History

A 15-year-old male with prior history of embryonal rhabdomyosarcoma presented with right hip and thigh pain associated with weight-bearing activities. He had previously undergone chemotherapy and radiation and was thought to have been in remission for a year prior to presentation. He initially presented to the hematology-oncology service, and a workup was initiated to determine the source of his pain. Radiographs of his pelvis and right femur were obtained, which demonstrated a radiolucent lesion in his right proximal femur. To better visualize the lesion, an MRI of the pelvis, including the right proximal femur, was ordered. This unfortunately demonstrated diffuse metastatic lesions throughout the pelvis and bilateral proximal femurs.

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Fig. 1 AP (Fig. 1) and Frog lateral (Fig. 2) pelvis radiographs demonstrating a radiolucent lesion in the superior femoral neck, without obvious fracture or periosteal reaction

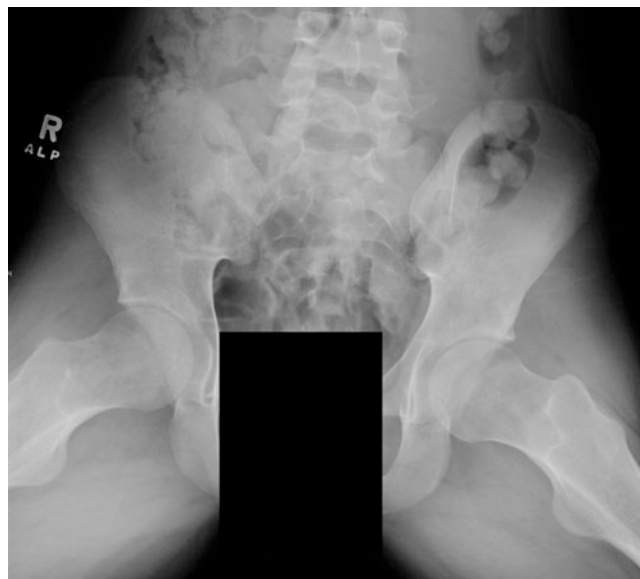


Fig. 2 AP (Fig. 1) and Frog lateral (Fig. 2) pelvis radiographs demonstrating a radiolucent lesion in the superior femoral neck, without obvious fracture or periosteal reaction

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, 5, 6, 7, and 8.

3 Preoperative Problem List

Impending pathologic fracture of right proximal femur.

4 Treatment Strategy

In this case, initial radiographs suggested a solitary lesion in the proximal femur. Given his history of prior embryonal rhabdomyosarcoma, an MRI was ordered to better visualize the lesion. Unfortunately, this demonstrated diffuse metastatic lesions throughout his pelvis and bilateral proximal femurs. In order to determine prognosis, an iliac crest bone biopsy was performed, which confirmed the diagnosis of recurrent metastatic embryonal rhabdomyosarcoma. A new regimen of chemotherapy and radiation was planned by the hematology and oncology service, although it was discussed that his recurrence portended a very poor prognosis.

The patient was felt to have a high risk of impending pathologic fracture, as calculated using Mirels' scoring system (see Table 1). It was felt that the peritrochanteric location of his lesion, functional pain level with activity, lytic nature of his lesion, and size of his lesion involving greater than 2/3



Fig. 3 Full-length AP and lateral radiographs of the right femur do not demonstrate any other apparent lesions in the remainder of the right femur

of the femoral neck gave him a score of 12, which is the maximum score in Mirels' scoring system. This correlates to a predictive fracture probability of 100%.



Fig. 4 Full-length AP and lateral radiographs of the right femur do not demonstrate any other apparent lesions in the remainder of the right femur

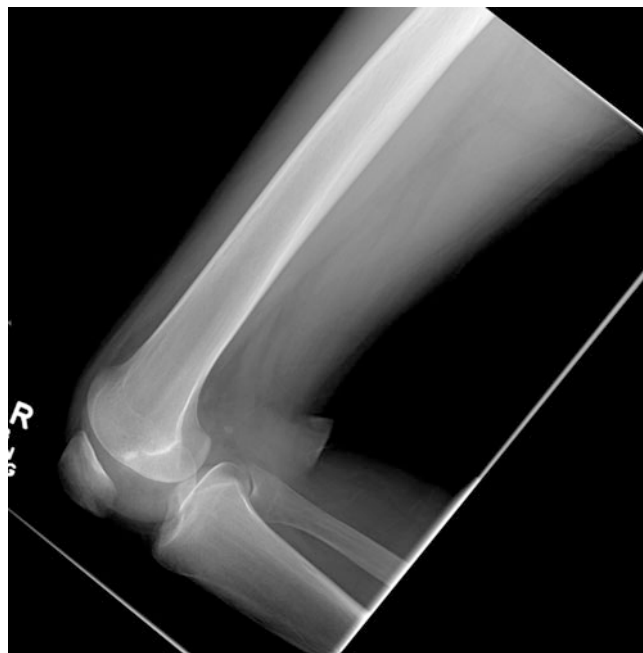


Fig. 6 Full-length AP and lateral radiographs of the right femur do not demonstrate any other apparent lesions in the remainder of the right femur

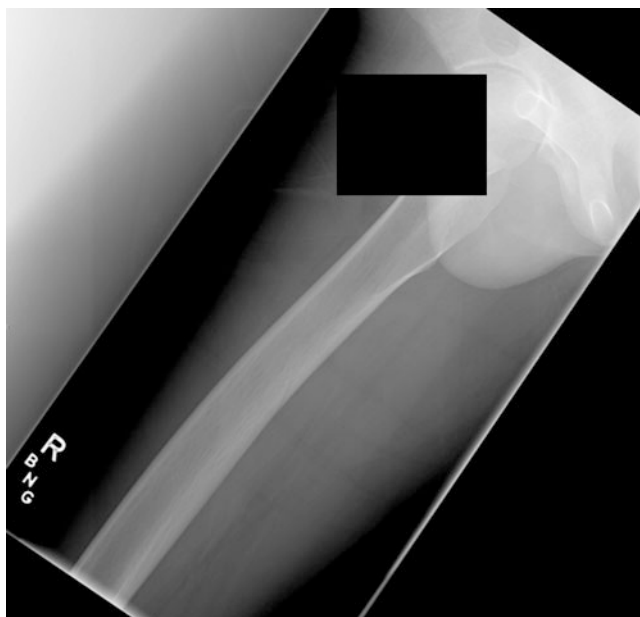


Fig. 5 Full-length AP and lateral radiographs of the right femur do not demonstrate any other apparent lesions in the remainder of the right femur

It was felt that as he demonstrated diffuse metastatic lesions throughout his skeleton, reaming of his femoral canal through the lesion would not ultimately change his

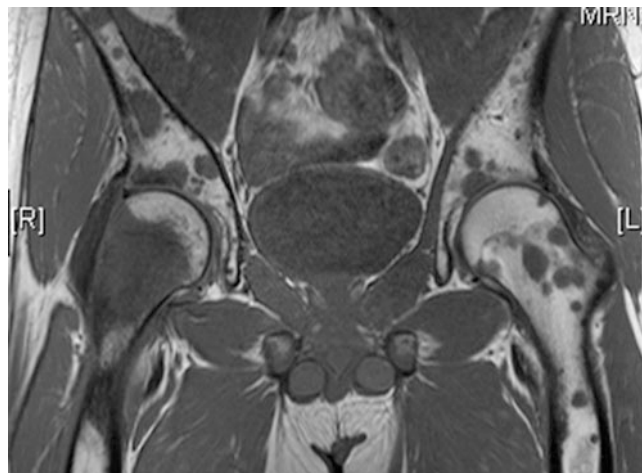


Fig. 7 Coronal MRI images demonstrating numerous metastatic lesions throughout the pelvis and bilateral proximal femurs

treatment or prognosis, and would only further add stability to his femur for any additional potential lesions in his femoral shaft. Therefore, it was felt that prophylactic placement of a cephalomedullary nail in his right femur would be beneficial to provide pain relief of his impending proximal femur fracture, and allow for greater quality of life during his expected treatments moving forward. Discussion was had with him and his family about potential prophylactic nailing of his contralateral femur as well, but it was deferred by his family as he was not yet having any pain on that side. He was deemed to be “medically optimized” by his hematology and

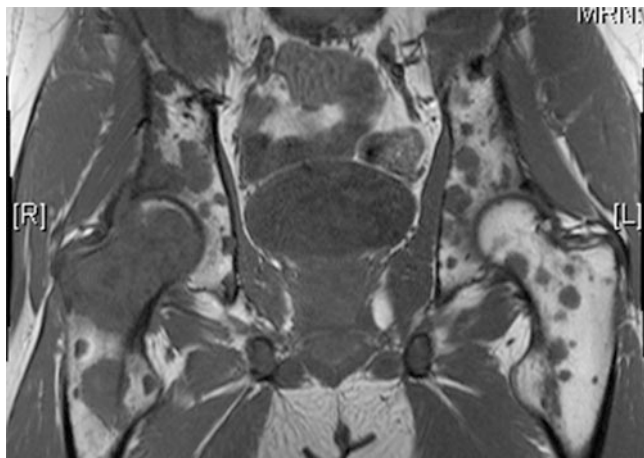


Fig. 8 Coronal MRI images demonstrating numerous metastatic lesions throughout the pelvis and bilateral proximal femurs

oncology team after preoperative blood work demonstrated satisfactory levels of hemoglobin, platelets, and normal clotting factors.

Postoperatively, he was made weight-bearing as tolerated, and he noted dramatic improvement in his pain during the first couple of weeks after surgery. He was instructed on gluteus medius strengthening for his Trendelenburg gait, and by his 6-week postoperative exam, he was completely pain-free, and participating in all desired activities.

5 Basic Principles

Any time a child presents with a fracture, one must be sure to determine if there are any potential comorbidities that may have added to the likelihood of fracture, such as poor bone quality, and whether or not a pathologic lesion may be suspected based on antecedent pain, or a suspiciously low mechanism of injury that would not be expected to be associated with certain types of fracture patterns. When there is concern based on history for possible pathologic fracture, adequate radiographs must be closely reviewed to determine if there is a pathologic lesion present that may have contributed to the fracture.

Determination of an underlying diagnosis for pathologic lesions is necessary prior to surgical treatment of the fracture. If a benign process is suggested based on radiographic criteria, or if a fracture occurs through a known benign pathologic lesion, then treatment can proceed based on the stability of the fracture. This may include conservative treatment with immobilization or casting, as well as potential biopsy, curettage and grafting, and fixation. When a malignant lesion is suspected, treatment should be conservative until a definitive biopsy can be performed to guide potential

Table 1 Mirels' scoring system for diagnosing impending pathologic fractures (originally described in the setting of metastatic disease in long bones in adults)

Variable	Score		
	1	2	3
Site	Upper limb	Lower limb	Peritrochanter
Pain	Mild	Moderate	Functional
Lesion	Blastic	Mixed	Lytic
Size	<1/3	1/3–2/3	>2/3

treatment. Biopsy must be meticulously planned so as to ensure the biopsy itself would not potentially contaminate the remainder of the bone, or additional anatomic compartments, and potentially alter the definitive treatment.

Other considerations that guide the type of treatment include whether the fracture is in the upper extremity which can often be treated with conservative means, or whether the fracture is in the weight-bearing portion of the lower extremities, that may be at increased risk of refracture. Also, the quality of the bone in the region of the lesion must be considered as it may influence the potential strength of the implant construct, and possibly influence which implant the surgeon may ultimately select.

Mirels' scoring system was originally described to predict the risk of impending pathologic fractures in adults in the setting of metastatic disease. In this case, the patient was skeletally mature, and had metastatic disease, so we felt this was clinically applicable. This may not be the case for the majority of pediatric pathologic fractures of the proximal femur.

6 Images During Treatment

Lesions with scores of 7 or lower can be safely irradiated without risk of fracture (<5%).

Lesions with score of 8 is suggestive of an impending fracture (~15%) and treatment should be guided by the surgeon's discretion.

Lesions with scores of 9 or greater is diagnostic of an impending fracture (>33% for a score of 9, increasing to 100% for a score of 12).

7 Technical Pearls

Prior to addressing the fracture, make sure an underlying diagnosis for the pathologic lesion is known, or that a benign process can essentially be assured based on radiographic criteria.

Be sure to account for any deformity that may be present in the bone from repeated microfractures, as can occur in fibrous dysplasia. Standard implants may not be compatible with significant deformity, and may require alternative methods of fixation, or concomitant osteotomies at the time of surgery.

Consideration should be made to ensure the portion of the bone that the implant is relying on for fixation, should be of good bone quality to avoid loss of fixation during the healing process.

Cephalomedullary nails are particularly useful to address proximal femur, peritrochanteric, or femoral neck fractures, as they span the entire proximal femur, to avoid the potential for adjacent stress risers that may result in additional fractures. If the child is too small to accommodate an intramedullary nail, then flexible nails augmented with proximal screw fixation or bent wires with cerclage can be considered.

8 Outcome Clinical Photos and Radiographs

See Figs. 9, 10, 11, 12, 13.

9 Avoiding and Managing Problems

If a benign process is almost assured based on radiographic appearance, biopsy can be performed at the time of surgical stabilization, with or without curettage and grafting.

Cultures should always be obtained when performing a biopsy of a bony lesion.

Intramedullary fixation should only be considered when there is no concern for potential dissemination of the pathologic lesion throughout the remainder of the bone.

Surgeons should be comfortable with various types of constructs to provide stability for unstable fractures in the setting of poor, or limited bone purchase, and try to avoid damage to adjacent growth plates.

Consideration should be made to be more aggressive in treating even benign lesions when potential fracture through the lesion may have increased morbidity or complications, such as those through the femoral neck, that carry an increased risk of avascular necrosis or malunion.

Pathologic fractures that present through a malignant lesion, should ideally have the fracture treated conservatively initially, until definitive diagnosis can be identified from biopsy. Care should be taken to obtain a biopsy from a representative portion of the lesion, and avoid inclusion of callus, which may appear histologically similar to an osteosarcoma.



Fig. 9 AP and lateral radiographs of the right femur demonstrating placement of a cephalomedullary nail



Fig. 10 AP and lateral radiographs of the right femur demonstrating placement of a cephalomedullary nail



Fig. 11 AP and lateral radiographs of the right femur demonstrating placement of a cephalomedullary nail



Fig. 13 AP and lateral radiographs of the right femur demonstrating placement of a cephalomedullary nail



Fig. 12 AP and lateral radiographs of the right femur demonstrating placement of a cephalomedullary nail

10 Cross-References

- ▶ [Femoral Neck Fractures in Children](#)
- ▶ [Pathologic Femoral Shaft Fracture](#)
- ▶ [Pathological Fracture of the Proximal Humerus](#)

References and Suggested Reading

- Boardman MJ, Herman MJ, Buck B, Pizzutillo PD (2009) Hip fractures in children. *J Am Acad Orthop Surg* 17(3):162–173. Review
- Mirels H (1989) Metastatic disease in long bones. A proposed scoring system for diagnosing impending pathologic fractures. *Clin Orthop Relat Res* 249:256–264
- Ortiz EJ, Isler MH, Navia JE, Canosa R (2005) Pathologic fractures in children. *Clin Orthop Relat Res* 432:116–126
- Wai EK, Davis AM, Griffin A, Bell RS, Wunder JS (2001) Pathologic fractures of the proximal femur secondary to benign bone tumors. *Clin Orthop Relat Res* 393:279–286

Proximal Femoral Stress Fractures

Josh Murphy, Lisa K. O'Brien, and Sally Corey

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Abstract

Proximal femoral stress fractures are a rare but serious overuse injury that can be indicative of improper physical

training habits or an underlying malnutrition disorder. These fractures are much more common in populations with high activity levels such as the military or athletes who require repetitive action, like runners. Patients typically present with insidious onset of activity-related pain that progresses if activity levels are not modified. A thorough history should be obtained on the patient's duration and frequency of training, dietary habits, and, if applicable, menstrual history. Magnetic resonance imaging (MRI) is the most sensitive test for diagnosing stress fractures and can be used if plain radiographs are negative but clinical suspicion persists. Treatment is often dictated by fracture location. Fractures about the inferior-medial aspect of the femoral neck are more common and can be treated nonoperatively, while fractures about the superior-lateral aspect of the femoral neck require operative fixation. Treatment outcomes are typically good. Failure to recognize a proximal femoral stress fracture can result in devastating complications, such as displacement of the

Disclaimer The views expressed in this chapter are those of the author(s) and do not necessarily reflect the official policy of the Department of Defense, Department of Army, US Army Medical Department, or the US Government. Verbal consent was obtained from the patient described in this chapter to use her clinical and imaging data.

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fracture and osteonecrosis. The following case highlights an operative femoral neck stress fracture in a military recruit.

1 Brief Clinical History

A 19-year-old female presented with left hip pain of 2 months duration. The pain began shortly after a sudden increase in physical activity after beginning her military training; there was no specific injury. The pain began gradually and was worse with high impact activities, such as running. Symptoms progressed to the point that she could no longer ambulate without pain and she sought medical attention. She denied any eating disorders or amenorrhea.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4.

3 Preoperative Problem List

- Sudden increase in physical activity leading to excessive mechanical stress
- Tension-sided femoral neck stress fracture, requiring surgical fixation

4 Treatment Strategy

Treatment is often dictated by the location of the stress fracture. Nonoperative management is appropriate for non-displaced compression-sided stress fractures, or fractures located along the inferior-medial aspect of the femoral neck, that do not extend past 50% of the width of the femoral neck. Nonoperative treatment modalities include limited weight bearing, activity restriction, and appropriate analgesia.

Indications for surgical management are compression-sided stress fractures that have shown no improvement with nonoperative treatment or have propagated >50% across the width of the femoral neck, or stress fractures that originate from the tension-side (superior-lateral) of the femoral neck. These fractures can be treated with in situ percutaneous screw fixation.

In the event the fracture displaces, it should be treated in a timely fashion with anatomic reduction and screw fixation.



Fig. 1 Radiographs can often be negative for fracture during initial presentation. In this case, an anteroposterior (AP) radiograph of the patient's left hip at the onset of symptoms reveal a tension-sided fracture of the femoral neck

5 Basic Principles

5.1 Positioning

Place the patient supine on a fracture table with the pelvis level and the contralateral lower extremity abducted, scissored, or safely secured to the central bar of the fracture table. A large C-arm fluoroscopic machine can then easily maneuver between the legs from the contralateral side of the operative extremity. The arm ipsilateral to the injured hip can be draped and secured across their body (Fig. 5). Prior to starting the procedure, confirm with the C-arm that the fracture has remained nondisplaced after positioning.

5.2 Surgical Technique

Typical screw configuration is an inverted triangle (Figs. 7 and 8). Guide pins can be placed through individual poke holes or through one longitudinal incision. Use fluoroscopic guidance to drill the inferior guide pin along medial cortex of femoral neck into femoral head on the AP view, stopping approximately 5 mm within the subchondral bone. This pin should be centered in the femoral neck on the cross-table lateral view.

The second and third guide pins are placed superior-anterior and superior-posterior to the first guide pin. Drill

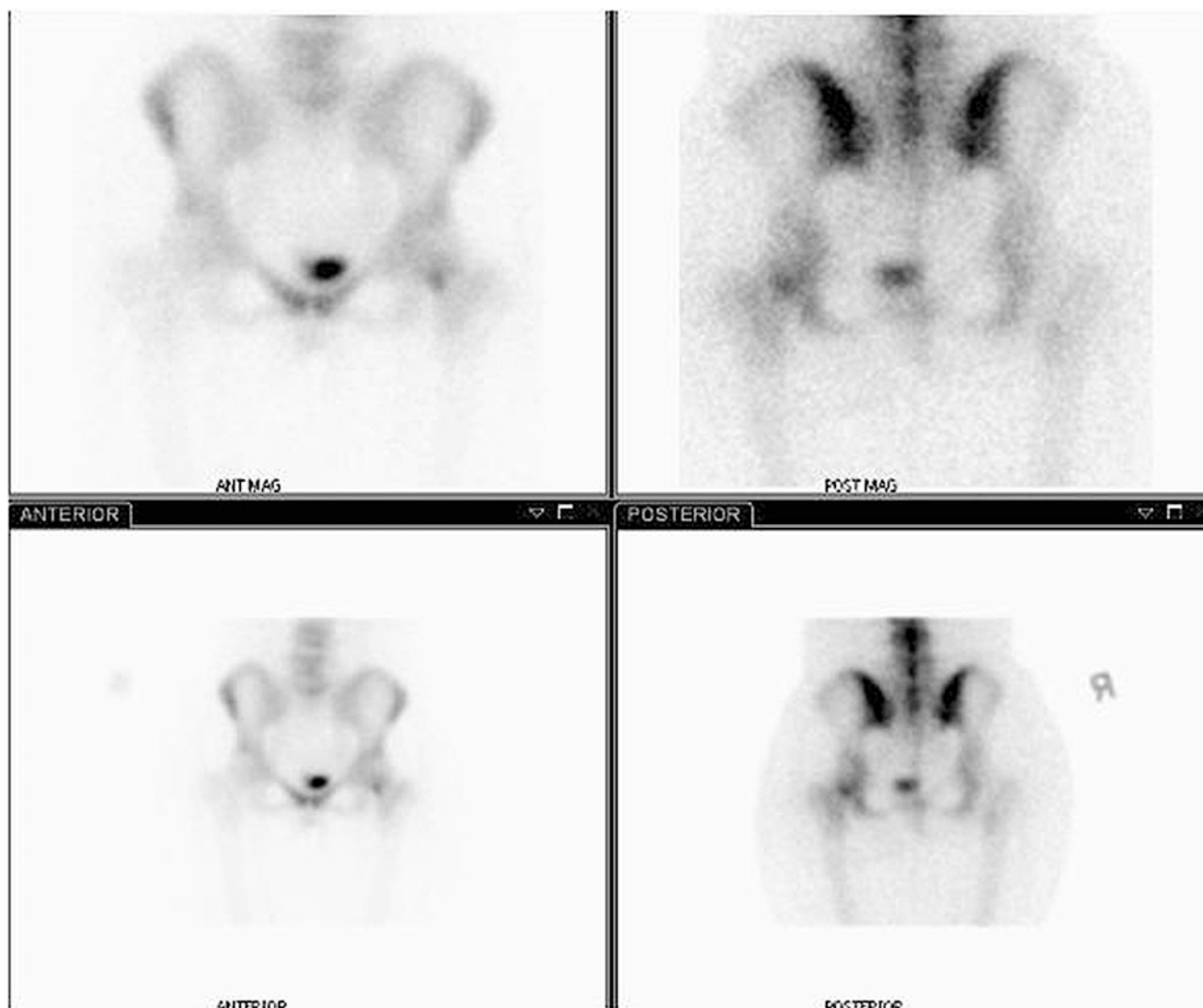


Fig. 2 Bone scans are sometimes obtained in the workup of stress fractures and illustrate increased uptake in the region of the fracture. Bone scans give less information than magnetic resonance images and also are not positive until 24–72 h after onset of injury

guides are available if necessary for placement of these pins that reference off of the inferior guide pin.

Screw lengths are determined by externally measuring the exposed guide pin length with an appropriate measuring device.

A cannulated drill is then placed over each guide pin and drilled to 5–10 mm short of the end of the pin.

The screws are introduced into the bone over their respective guide pin. All three screws should be tightened simultaneously to ensure uniform compression across the fracture.

The guide pins are removed and final fluoroscopic images are obtained. The incision(s) is/are irrigated and closed with sutures of surgeon's choice (Mullis and Anglen 2011).

6 Images During Treatment

See Figs. 5, 6, 7, and 8.

7 Technical Pearls

The inferior screw should be contiguous with the calcar along the posterior-inferior neck.

Obtain parallel configuration of the screws in the femoral neck.



Fig. 3 T2 coronal magnetic resonance images (MRI) of the left hip at the onset of symptoms reveal a complete, nondisplaced femoral neck fracture



Fig. 4 T1 coronal MRI of the left hip re-demonstrates the femoral neck fracture



Fig. 5 Patient may be placed on a fracture table with the arm taped over the chest. Radiographs are obtained prior to prepping and draping the patient to ensure proper images can be obtained



Fig. 6 The patient is prepped and draped

Avoid starting screws distal to the lesser trochanter. This may increase the risk of a subtrochanteric fracture postoperatively.

8 Outcome Clinical Photos and Radiographs

See Figs. 9 and 10.



Fig. 7 AP radiograph shows an inverted triangle configuration with the inferior most screw along the inferior aspect of the femoral neck



Fig. 9 AP radiograph taken 5 months after surgery reveals a well-healed femoral neck fracture



Fig. 8 Cross-table lateral radiograph shows a parallel configuration of the screws across the femoral neck fracture



Fig. 10 Cross-table lateral radiograph taken 5 months after surgery reveals a well-healed femoral neck fracture

9 Avoiding and Managing Problems

Risk factors associated with developing a femoral neck stress fracture include (de Weber 2017):

- Prior stress fracture
- Sudden increase in intensity or duration of physical activity
- Poor biomechanics
- Menstrual irregularity
- Female gender
- Low body mass index
- Decreased bone density
- Diet low in calcium and vitamin D or calorie-restricted
- Smoking or alcohol use

Engaging in an exercise program with gradual changes in intensity, periodization, cross-training, and appropriate rest is the key to injury prevention. Regular weight-bearing exercise can also help to increase bone density by way of Wolff's Law, which states that bone will remodel in response to the mechanical stresses that it receives.

Managing dietary habits is another key component for preventing stress fractures. Females with evidence of the female athlete triad (eating disorders, secondary amenorrhea, osteopenia) are at greatest risk. A thorough dietary history should be obtained to determine adequacy of calories, vitamin D, and calcium intake. Recommendations of vitamin D for children, adolescents, and adults populations include 600 International Units (IU) of vitamin D each day. It is recommended that adolescents receive 1,300 mg of calcium each day, while young adults older than age 19 receive 1,000 mg daily (Table 1).

Consider other differential diagnoses during the workup of a proximal femoral stress fracture. Be sure to rule out serious conditions such as septic arthritis, osteomyelitis, tumor, or avascular necrosis if suspected clinically. Other differential diagnoses or associated injuries can include

Table 1 Institute of Medicine 2011 dietary reference intakes for calcium and vitamin D

Age range	Vitamin D	Calcium
4–8 years	600 IU	1,000 mg
9–18 years	600 IU	1,300 mg
19–50 years	600 IU	1,000 mg
51–70 years	600 IU	1,200 mg

muscle strains, iliopsoas tendinitis, snapping hip syndrome, labral tears, greater trochanteric bursitis, or femoral-acetabular impingement.

Acknowledgments The authors would like to acknowledge John Corley, medical photographer, for his contribution to this chapter.

10 Cross-References

- [Tibial Shaft Stress Fracture](#)

References and Suggested Readings

- de Weber K (2017) Overview of stress fractures. Resource document. UpToDate. <https://www.uptodate.com/contents/overview-of-stress-fractures>. Accessed 27 Mar 2017
- Mullis B, Anglen J (2011) Open reduction and internal fixation and closed reduction and percutaneous pinning of femoral neck fractures. In: Wiesel S (ed) Operative techniques in orthopaedic surgery. Lippincott Williams & Wilkins, Philadelphia, pp 521–532
- Ross AC, Manson JE, Abrams SA, Aloia JF, Brannon PM, Clinton SK, Durazo-Arvizu RA, Gallagher JC, Gallo RL, Jones G, Kovacs CS, Mayne ST, Rosen CJ, Shapses SA (2011) The 2011 Dietary Reference Intakes for Calcium and Vitamin D: what dietetics practitioners need to know. *J Am Diet Assoc* 111(4):524–527

Greater Trochanter Fracture

Courtney O'Donnell and Nicole Michael

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Abstract

Fractures of the greater trochanter in the pediatric patient are rare injuries in isolation. Most nonpathological fractures result from high-energy trauma and can often involve associated fractures of the proximal femur. Treatment is guided by degree of displacement and extent of associated injury to the proximal femur. Minimally displaced fractures of the greater trochanter can be treated nonsurgically with spica casting in young children (<5 years old) and with protected weight-bearing in older children. Anatomic reduction and stable fixation are indicated for nearly all displaced hip fractures in children. Fixation options range from screw fixation of the greater trochanter alone, to a construct including a compression screw and side plate or fixed angle device (blade plate; proximal femoral locking plate) in proximal

femur fractures. In displaced fractures, achievement of fracture stability is prioritized over the preservation of the proximal femoral physis and/or the trochanteric apophysis. Complications after this injury are frequent in children due to the vulnerability of the proximal femur to vascular or physeal injury. Avascular necrosis, angular deformity of the proximal femur, premature physeal closure, and nonunion are complications that account for poor outcomes. These injuries require careful follow-up until both fracture healing and skeletal maturity.

1 Brief Clinical History

Greater trochanter fractures can occur in isolation as a physeal injury or involve associated injury to the proximal femur, and usually occur because of high-energy trauma or an underlying pathologic condition. Nonaccidental trauma should be considered in very young children. Initial assessment of the entire child must exclude the possibility of life-threatening injuries and other skeletal injuries. Other

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differential diagnoses for hip pain should be considered. The possibility of proximal femoral epiphysiolysis, a physeal fracture of the hip, must be considered in the newborn who has painful and limited hip motion combined with a history of a difficult delivery requiring forceful extraction. Children with displaced proximal hip fractures are unable to bear weight and frequently lie with a shortened externally rotated lower extremity. Movement of the possibly fractured hip is avoided. Vascular examination must include palpation of the popliteal and dorsalis pedis pulses compared to the contralateral limb and ankle-brachial indices to rule out associated vascular injury. To establish a diagnosis, an AP pelvis and cross-table lateral radiograph should both be performed.

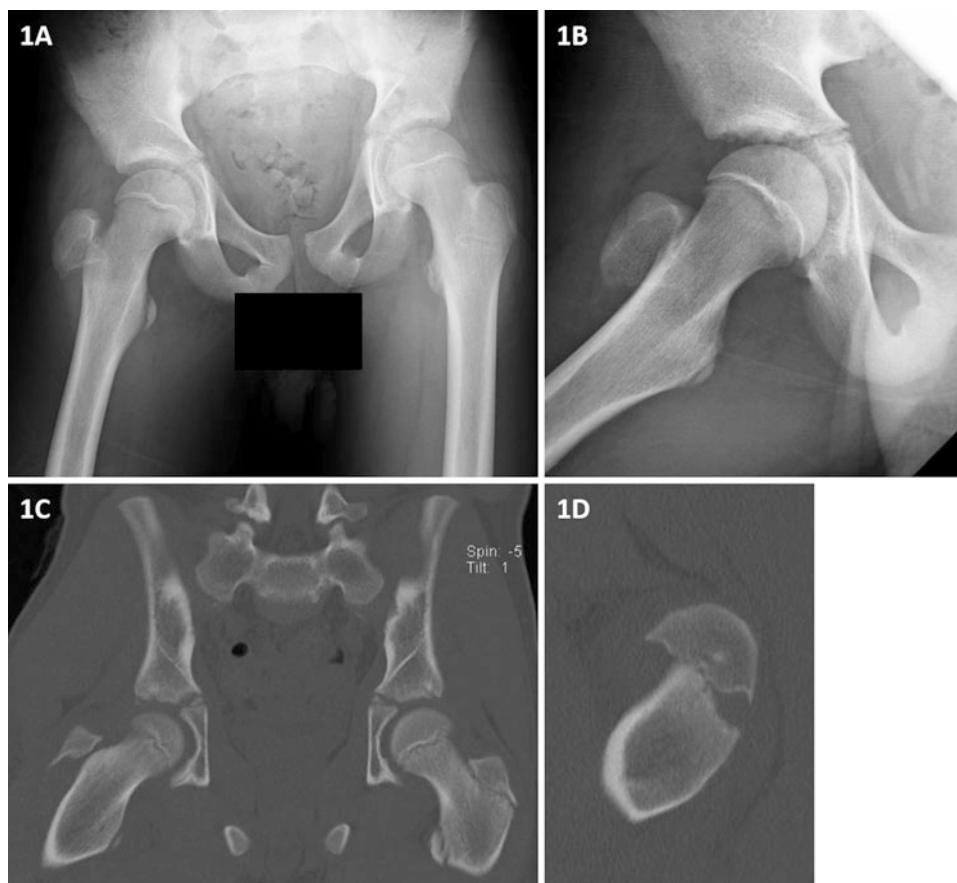
2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Suspected physeal injury
2. Displacement of fracture, detachment, and shortening of abductor mechanism

Fig. 1 Case 1: AP (a) and lateral (b) radiographs of a 13-year-old male with right displaced greater trochanteric fracture after an acute wakeboarding accident. Coronal (c) and sagittal (d) cuts from pelvis computed tomography (CT) scan after acute injury demonstrate a displaced fracture through the greater trochanteric apophysis

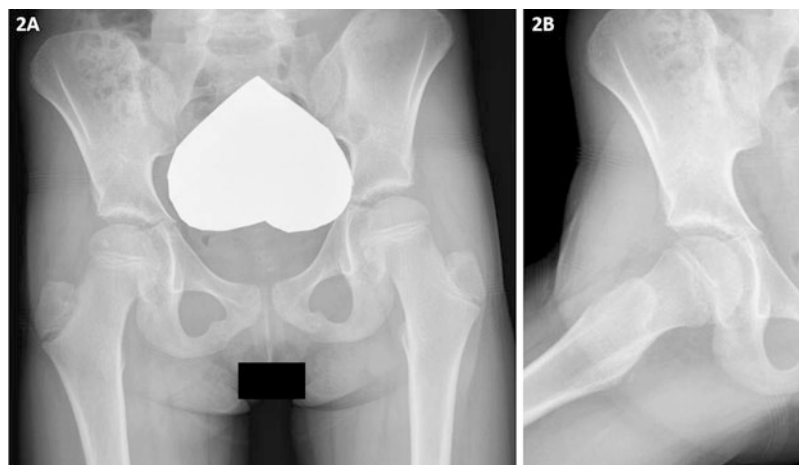


3. Associated injury to the proximal femur – subtrochanteric or femoral neck involvement
4. Necessity of advanced imaging – CT or MRI
5. Urgency of treatment
6. Necessity for surgical treatment
7. Necessity of capsulotomy if femoral neck fracture component present

4 Treatment Strategy

Treatment decision is based on the following factors: patient age, displacement of the greater trochanter, and associated injury to the proximal femur. In children under the age of 5, early spica casting can be used if the reduction is acceptable. However, operative management is indicated if satisfactory reduction cannot be achieved in a cast, regardless of age. Minimally displaced greater trochanter physeal fractures will be identified by a pelvis AP radiograph, which will show physeal widening and irregularity (Case 2), and can be treated with a period of 6–12 weeks of protected weight bearing with crutches and avoidance of active abduction. Displaced greater trochanter fractures typically require operative management to obtain and maintain fracture reduction and restore the abductor

Fig. 2 Case 2: AP (a) and lateral (b) radiographs of an 8-year-old female dancer with 3 months of right hip pain demonstrating physeal widening at the greater trochanteric apophysis suggestive of a stress injury



mechanism (Case 1). Surgical approach is determined based on surgeon preference and involvement of the proximal femur; anterolateral (Watson-Jones), combined anterior (Modified Smith-Peterson) and direct lateral, or a surgical dislocation approach (Gibson interval) have all been utilized for this injury. Surgical treatment of greater trochanteric fractures is dependent on careful preoperative planning and implant selection specific to the fracture type. Schanz pins (2.5 or 4.0 mm) can be used as joysticks for reduction. Fixation of the proximal femur can be carried out with 6.5 mm/7.3 mm partially or fully threaded cannulated screws (subcapital or transcervical type fractures), compression hip screw with side plate (basicervical/intertrochanteric type fractures), or a proximal femoral locking plate (comminuted, complex, subtrochanteric fractures). The greater trochanteric fragment must be anatomically reduced and fixed with 3.5 or 4.5 fully threaded screws. Reduction of this fragment can be assisted with a pointed reduction clamp (Weber) or ball-spike pusher; washers can also be used to assist in compression.

5 Basic Principles

Obtaining and maintaining anatomic reduction and stable fixation of proximal femur by avoidance of varus and/or retroversion (common deformity) must be prioritized. The blood supply to the proximal femur must be preserved by urgent reduction and fixation of fractures with a femoral neck component, appropriate respect for anatomy of the epiphyseal vasculature, as well as urgent capsulotomy when necessary. The abductor lever arm and length-tension relationship must be restored with anatomic reduction of the greater trochanter. Fixation in the femoral neck must be prioritized with subsequent fixation of the greater trochanter; the operative strategy must anatomically reduce all pieces of a comminuted fracture.

6 Images During Treatment

See Figs. 3 and 4.

7 Technical Pearls

Preoperatively, complete imaging workup is essential for careful diagnosis. One must maintain a high suspicion for associated injury to the femoral neck and subtrochanteric region, or associated injury to the pelvis/acetabulum. Intraoperatively, careful planning and implant selection appropriate for fracture pattern is essential. Reduction can be provisionally obtained with Schanz pins or K-wires to ensure anatomic reduction. Postoperatively, protected weight-bearing should be enforced for a minimum of 6–8 weeks and fracture healing followed closely. The greater trochanteric bone stock is often thin and has cancellous quality; protected weight-bearing can be extended to 12 weeks to minimize the risk of postoperative failure.

8 Outcome Clinical Photos and Radiographs

See Figs. 5 and 6.

9 Avoiding and Managing Problems

Due to the significant contribution of the greater trochanteric apophysis to the growth of the proximal femur, these injuries can have implications beyond fracture healing and need to be followed closely. The sequelae of a fracture to the greater trochanter can include coxa valga (with relative overgrowth of the femoral epiphysis to the greater trochanteric



Fig. 3 Case 1: T1 postcontrast coronal MRI (a) 2 months after acute injury demonstrating intact epiphyseal perfusion without signs of avascular necrosis. AP (b) and lateral (c) views of the right hip 5 months post-injury with interval healing at the greater trochanter. Greater trochanteric fragment has healed in a relatively anterior position

apophysis) and/or avascular necrosis (AVN) with resultant femoral head deformity. AVN is likely the result of a vascular insult to the epiphyseal vessels at the time of injury. Detection of AVN typically occurs within the first 18 months following the injury, and yearly radiographic surveillance is recommended for a minimum of 2 years after injury. Loss of femoral head sphericity on plain radiographs may be the first sign of AVN. An MRI will confirm



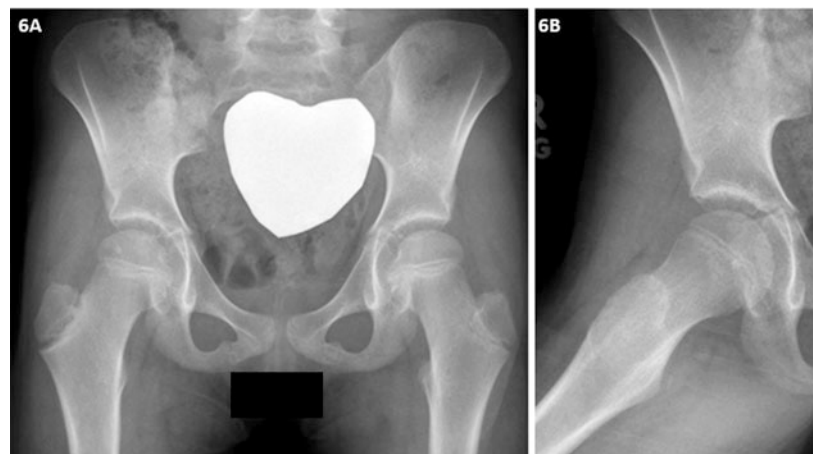
Fig. 4 Case 2: Coronal STIR MRI sequence (a) of right hip with physeal widening and bony edema surrounding greater trochanteric apophysis suggestive of stress injury with physeal widening

this diagnosis early in the process by a single-density line on T1-weighted images representing the necrotic-viable bone interface, and a double-density line on T2-weighted images representing the hypervascular granulation tissue at the necrotic-viable bone interface. Coxa valga can result from continued growth of the femoral epiphysis and closure of the greater trochanteric apophysis. Premature physeal closure can also result in future limb length discrepancy or coxa vara. Close clinical and radiographic follow-up is recommended for these children beyond fracture healing into skeletal maturity to appropriately manage resultant complications.

Fig. 5 Case 1: Coronal STIR MRI sequence (a) and sagittal T2 fat-saturation MRI sequence (b) demonstrating subchondral sclerosis with area of disrupted vascularity suggestive of avascular necrosis at 9 months post-injury. AP (c) and lateral (d) radiographs of the right hip at 9 months post-injury which demonstrate a small area of sclerosis and collapse concerning for avascular necrosis. Femoral neck is shortened (coxa breva) and greater trochanter has healed in a relative anterior position



Fig. 6 Case 2: AP (a) and lateral (b) radiographs 1 year after minimally displaced greater trochanteric stress fracture. Interval healing demonstrated with incomplete physeal closure. No signs of avascular necrosis



10 Cross-References

► [Pathologic Proximal Femur Fracture](#)

References and Suggested Reading

Boardman MJ, Herman MJ, Buck B, Pizzutillo PD (2009) Hip fractures in children. *J Am Acad Orthop Surg* 17(3):162–173

Brousil J, Hunter JB (2013) Femoral fractures in children. *Curr Opin Pediatr* 25(1):52–57

Swiontkowski M (2003) Fractures and dislocations about the hips and pelvis. Elsevier, *Skeletal Trauma in Children*

Zalavras CG, Lieberman JR (2014) Osteonecrosis of the femoral head: evaluation and treatment. *J Am Acad Orthop Surg* 22(7):455–464

Hip Dislocation with Midshaft Femur Fracture

Brandon Lucas and Kevin E. Klingele

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Abstract

Midshaft femur fractures with associated traumatic hip dislocations are a rare injury pattern in the pediatric population. These injuries are caused by high-energy mechanisms, such as an MVC or a fall from height. Management of this injury pattern first focuses on reduction of the hip, followed by surgical intervention of the femur fracture itself. Reduction of the hip, depending on timing, takes place in the emergency department or the operating room, followed by fixation of the femur fracture. There are a multitude of potential associated injuries; therefore it is of utmost importance to perform a thorough and adequate trauma evaluation. This case presents the management strategy of a 15-year-old male with a left hip dislocation and associated ipsilateral midshaft femur fracture.

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1 Brief Clinical History

A 15-year-old male presented to the emergency department as a level 1 trauma after being involved in an MVC. He was a restrained passenger in the backseat of a vehicle that was rear-ended. He was extricated from the vehicle by EMS and complained of left leg and hip pain upon initial evaluation. On exam, there was a visible deformity noted about the left thigh. It was swollen and tender to palpation. There was also tenderness to palpation about the left knee with a visible effusion. He had subjective numbness to the lateral aspect of his left foot, but otherwise his neurovascular exam was intact. No other injuries were noted during the primary and secondary surveys. Radiographs demonstrate a left midshaft femur fracture with an associated ipsilateral hip dislocation, as well as a likely PCL avulsion injury (Fig. 1). This was confirmed with a postoperative knee MRI. The patient was taken urgently to the OR for closed reduction of his hip and open reduction internal fixation of his femur fracture.



Fig. 1 (a–e) AP and lateral radiographs of the femur showing a left hip dislocation and ipsilateral midshaft femur fracture, as well as knee radiographs suggestive of a PCL injury

2 Preoperative Radiographs

See Fig. 1a–e

3 Preoperative Problem List

1. Left traumatic hip dislocation with femoral head fracture and posterior labral tear.
2. Left midshaft femur fracture.
3. Left PCL avulsion injury (confirmed with postoperative MRI).

4 Treatment Strategy

Patients with multiple injuries sustained via a high-energy mechanism should receive a thorough trauma evaluation by the emergency department and trauma services. Once the initial trauma evaluation and treatment have occurred, focus can be given to specific orthopedic injuries. Management of this patient's injuries first focuses on a concentric reduction of the dislocated hip.

Reduction in this patient, given the associated ipsilateral femoral shaft fracture and need for operative intervention, was not performed in the emergency department. If there is an expected delay to the OR, however, reduction should initially be attempted in an expedited fashion (Hung et al. 2012). Sufficient sedation is vital for ease of reduction and to decrease any additional trauma to the hip or proximal femur. Outcomes after reduction are favorable, but risks include traumatic arthritis, myositis ossificans, and osteonecrosis of the femoral head (1). Reduction can be impeded by labral, capsule, or osteochondral injuries, requiring open reduction. Radiographs, as well as advanced imaging, should be obtained after reduction to ensure a concentric joint and to assess for associated injuries. Associated injuries include femoral head or neck fractures, as well as proximal femoral physeal injuries. Recent studies suggest a high incidence of labral pathology, usually seen on postreduction imaging via the so-called acetabular fleck sign (Klingele et al. 2016).

Isolated femoral shaft fractures in this age group should initially be treated with provisional traction in the emergency department until taken to the operating room at a later time. Definitive treatment of fractures of this type varies with age. Patients 11 years of age and older, as is the case with this patient, are candidates for either flexible or rigid intramedullary nails (Hubbard et al. 2018). Those under 100 lbs. are generally treated with flexible nails, while those

over 100 lbs. are treated with either a rigid nail or sub-muscular plating. Open reduction internal fixation via sub-muscular plate application is also acceptable depending on fracture pattern.

Treatment strategy for this patient includes initial closed reduction of the dislocated hip; open reduction internal fixation of the ipsilateral femoral shaft fracture using a locking plate, as well as surgical hip dislocation and labral repair with suture anchors; and conservative management of the stable femoral head fracture, with plans for delayed treatment of the concomitant PCL injury. The patient underwent ORIF of his PCL avulsion injury 9 days after his initial surgery.

5 Basic Principles

The risk of femoral head avascular necrosis (AVN) increases with increased time to reduction in a dislocated hip (Kutty et al. 2001). These injuries should be reduced as urgently as possible given this risk. Those reduced within 4 hours had an AVN rate of approximately 6% (3). If closed reduction is unsuccessful, reduction results in a non-congruent hip joint, or associated injuries requiring evaluation are present, surgical intervention is necessary. In this case, surgical hip dislocation was used to address the hip joint. Other approaches, depending on the direction of dislocation, include the Smith-Petersen and Kocher-Langenbeck approaches. Early results have shown that surgical hip dislocation has been shown to be a safe and effective means to treat an incomplete reduction of the pediatric traumatic hip dislocation (Podeszwa et al. 2015). It is effective for identification and treatment of acute intra-articular pathology (4), such as associated proximal femoral fractures or labral tears, which were both discovered in this patient intraoperatively. These injuries are then addressed and treated as they are discovered. In the setting of a traumatic posterior hip dislocation, associated posterior labral tears were found in 82% of patients, and femoral head fractures were found in 18% (4).

Given the necessity for operative intervention regarding the femoral shaft fracture, the associated hip dislocation and likely need for surgical evaluation of the hip joint were addressed with a surgical hip dislocation during the same operation. A postoperative MRI confirmed the PCL injury. This can be addressed in a staged fashion at a later date.

6 Images During Treatment

See Fig. 2a, b.

7 Technical Pearls

Postreduction imaging of the hip is crucial to rule out any joint incongruity or entrapped fragments as this is associated with poor outcomes including early-onset arthritis and is an indication for open surgical management (Novias et al. 2016). Failure to obtain a concentric joint after reduction has been reported to be up to 25% in children and adolescents following a traumatic posterior dislocation (5).

In patients with an associated ipsilateral ligamentous knee injury, as well as potential proximal femoral pathology, options for femoral shaft fracture fixation are somewhat limited. We elected to open reduce and internally fixate the femur using a locking plate to avoid violating both the knee and the proximal femur, as future procedures in both the knee and the hip were necessary.

Associated bony lesions of the acetabulum or femoral head causing instability in children are thought to be less likely but may be underestimated due to incomplete ossification and the inability to see cartilage on XR/CT (5). Therefore, it is very important to thoroughly evaluate any hip pathology using direct visualization. There is a high rate of labral pathology with traumatic dislocations that necessitates adequate evaluation intraoperatively. In this case, surgical hip dislocation was used to evaluate the hip joint directly and address the associated hip pathology.

8 Outcome Clinical Photos and Radiographs

See Fig. 3a, b and Fig. 4

9 Avoiding and Managing Problems

A traumatic hip dislocation with an associated femoral shaft fracture is usually the result of a high-energy mechanism, thus making a complete traumatic workup essential for patient care. Orthopedic injuries are managed after initial ATLS and survey by the trauma team have been completed.

Hip dislocation should be reduced in a timely manner. As the time to reduction increases, so does the rate of AVN (3). Those reduced within 4 hours had an AVN rate of 6% (3).

A concentric reduction is necessary. If this is not achieved, surgical hip dislocation has been shown to be a safe and effective way to not only reduce the hip but also evaluate the joint for associated injuries (4).

Fig. 2 (a) AP of the femur status post ORIF with a lateral locking plate. (b) AP of the hip status post labral repair, showing fixation of the trochanteric osteotomy used during the surgical hip dislocation. Fixation achieved with two 3.5 mm fully threaded screws

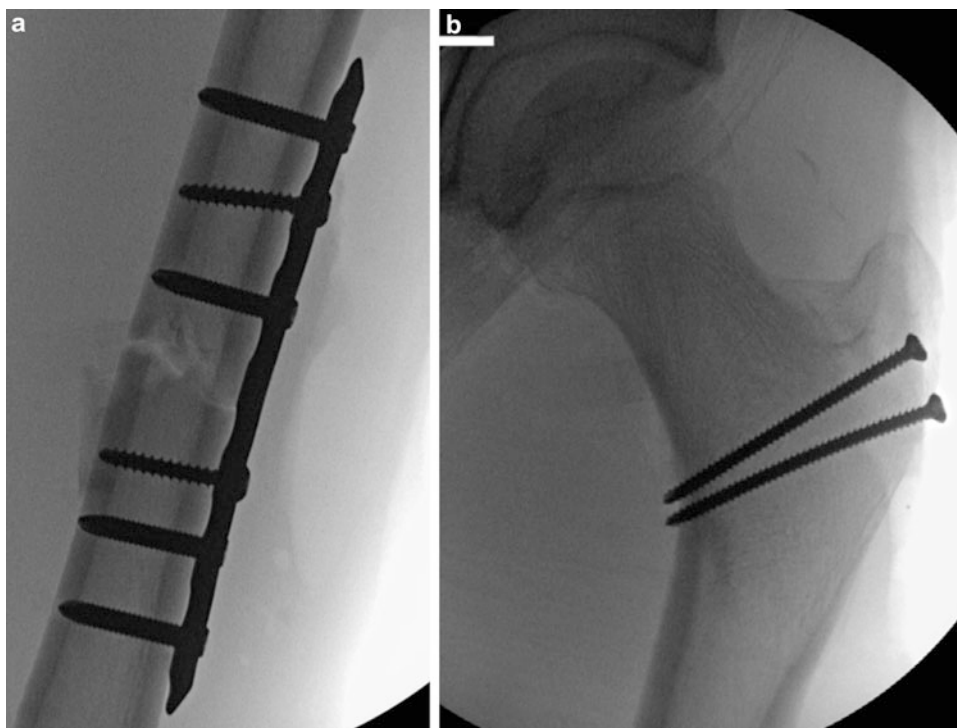


Fig. 3 (a and b) AP of the hip and femur 3 months post-op showing maintained fixation of the greater trochanter, as well as bridging callus of the femoral shaft



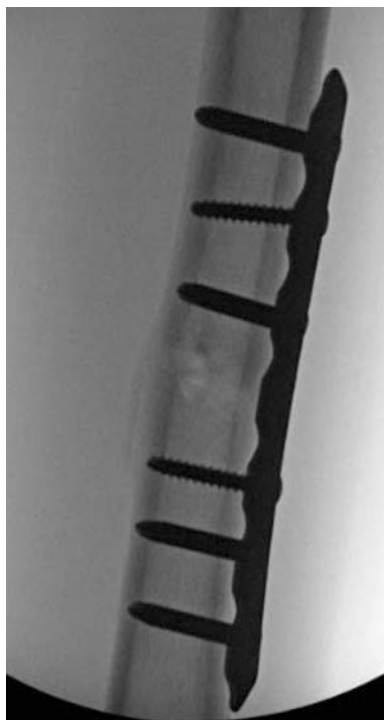


Fig. 4 Shows continued healing of the femoral shaft fracture 5 months post-op

In this specific injury pattern, the femoral shaft fracture requires surgical intervention. Therefore, the hip reduction was delayed until the patient got to the OR. This allowed for a more controlled environment and adequate sedation to decrease the risk of iatrogenic injury to the joint during reduction.

This patient also sustained an ipsilateral PCL injury. To avoid interfering with likely future procedures, both in the hip and the knee, open reduction and internal fixation of the femur using a locking plate was chosen versus fixation with anterograde or retrograde nailing.

10 Cross-References

► Hip Dislocation

References and Suggested Reading

- Hubbard EW et al (2018) Pediatric orthopedic trauma: an evidence-based approach. *Orthop Clin North Am* 49(2):195–210
- Hung NN et al (2012) Traumatic hip dislocation in children. *J Pediatr Orthop* 21(6):542–51
- Klinge K et al (2016) Traumatic, posterior pediatric hip dislocations with associated posterior labrum osteochondral avulsion: recognizing the acetabular "fleck" sign. *J Pediatr Orthop* 36(6):602–7
- Kutty S et al (2001) Traumatic posterior dislocation of hip in children. *Pediatr Emerg Care* 17(1):32–5
- Novias E et al (2016) Surgical hip dislocation for the treatment of intra-articular injuries and hip instability following traumatic posterior dislocation in children and adolescents. *J Pediatr Orthop* 36(7):673–9
- Podeszwa DA et al (2015) Surgical hip dislocation is safe and effective following acute traumatic hip instability in the adolescent. *J Pediatr Orthop* 35(5):435–42

Part V

Lower Extremity: Thigh, Knee, and Leg

Femoral Shaft Fracture: Pavlik Harness

Jason Read and Eric D. Shirley

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Abstract

A 6-week-old female infant presented with a leg pain after a witnessed fall. Radiographs demonstrated a non-displaced femur fracture. A Pavlik harness was selected to treat the fracture. The harness was well tolerated by the patient and family. The femur fracture healed successfully within 4 weeks without any complications.

witnessed fall which occurred while the parent was finding a pacifier for the child. Physical examination demonstrated a well-nourished child with intact skin and mild tenderness over the left femur. There were no signs of child abuse such as bruises, burns, or other skin lesions. The infant did not demonstrate irritability with range of motion of the hip, knee, and ankle joints. There were no neurovascular deficits. Initial radiographs demonstrated a nondisplaced left mid shaft femur fracture.

1 Brief Clinical History

A 6-week-old female infant presented to the emergency room after falling off the couch. The infant fell approximately 2 feet from the couch onto a carpeted floor. This was a

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Nondisplaced mid shaft femur fracture
2. Femur fracture in nonambulator

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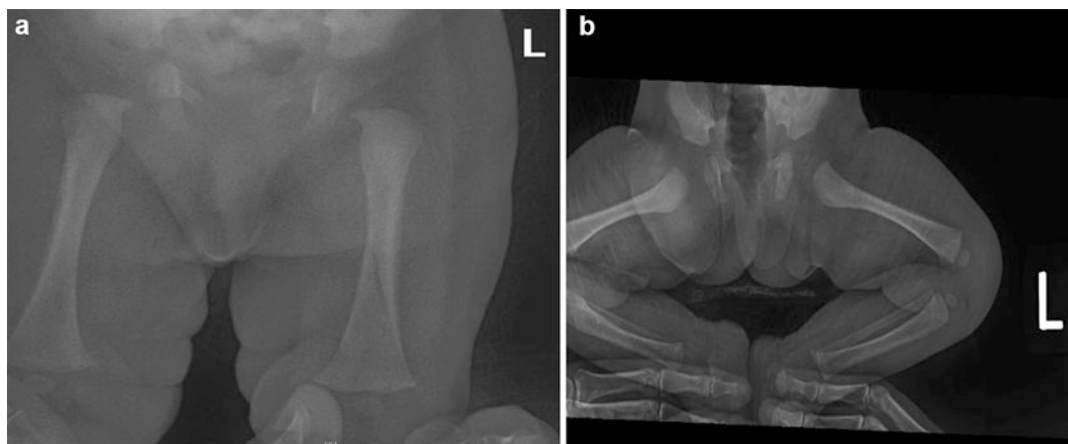


Fig. 1 Anteroposterior (a) and lateral (b) radiographs demonstrate the nondisplaced oblique left mid shaft femur fracture. The physes have a normal appearance

4 Treatment Strategy

Mid shaft femur fractures in infants up to 6 months of age can be treated successfully with either application of a Pavlik harness or a spica cast. Infants normally have a thick periosteum and high remodeling potential making most femoral shaft fractures stable. Pavlik harness treatment provides adequate stability better positioning of the fracture while healing takes place. Advantages of the Pavlik harness include ease of applying the harness, ease of diaper changes, less skin irritation than with casting, and the ability to adjust the harness for fracture manipulation. Further, application of the harness does not require anesthesia. In the event of excessive shortening greater than 2 cm and angulations greater than 30 degrees in an infant, spica casting may be used.

In treatment of a femoral shaft fracture in infants, a metabolic bone disease workup should be initiated if the radiographs are abnormal. Child abuse should also be ruled out as a cause of injury. Nonaccidental trauma is a leading cause of femoral shaft fractures in children before walking age. Therefore, a high suspicion of abuse must be considered along with a thorough history and physical looking for other possible injuries. As this was a witnessed fall and examination did not reveal any signs of child abuse, further workup for child abuse was not required.

5 Basic Principles

1. A high suspicion for child abuse is required in non-ambulators with femur shaft fractures. Additional evaluation for abuse may be required.



Fig. 2 Child resting comfortably in the harness

2. Radiographs should be closely inspected for pathologic processes such as abnormal physes from metabolic bone disease, bone tumors, and osteogenesis imperfecta.
3. The Pavlik harness may be used for children up to 6 months of age with diaphyseal femur fractures.
4. Complications of Pavlik harness use include femoral nerve injury due to excessive hip flexion.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

1. Applying the Pavlik harness with the patient's hip in moderate flexion and abduction will help align the proximal and distal femur fragments of displaced fractures (Fig. 2).

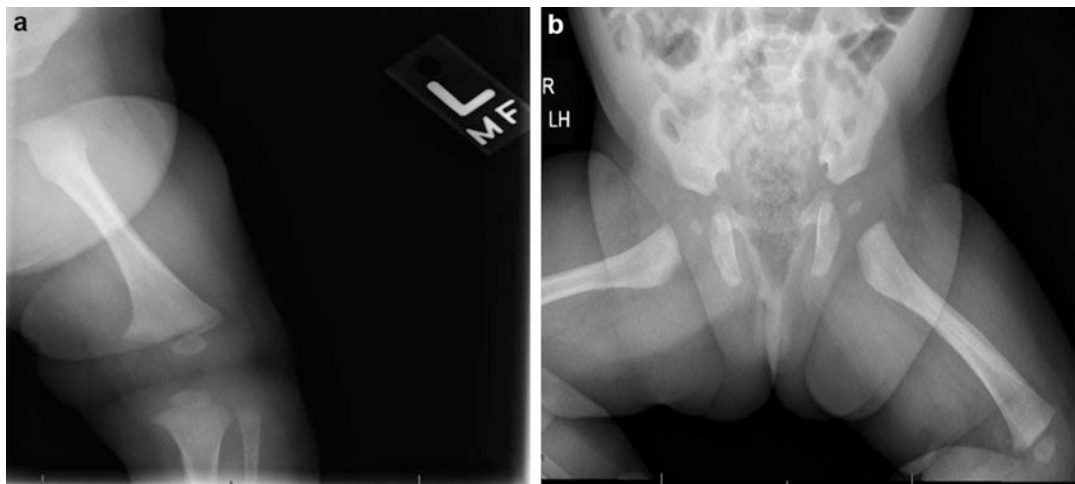


Fig. 3 Anteroposterior (a) and lateral (b) radiographs 4 weeks after injury demonstrate a healed mid shaft femur fracture

The anterior straps are used to adjust hip flexion while the posterior straps adjust abduction. Chest straps should not be excessively tight, the physician should be able to fit 1–2 fingers between the straps and the skin.

2. Intravenous or oral analgesia may be helpful during application. However, outpatient narcotics are discouraged in infants.
3. Families are instructed to monitor the skin closely for signs of irritation or breakdown.
4. The Pavlik harness should be worn 24 h each day as this will allow for alignment and healing to occur at the fracture site.
5. Initial follow up after applying the Pavlik harness is recommended within 1 week. This will allow for any adjustments to be made to the harness and to monitor for any complications including skin irritation or femoral nerve palsy.

8 Outcome Clinical Photos and Radiographs

See Fig. 3a, b.

9 Avoiding and Managing Problems

1. Attention to detail is required when applying the Pavlik harness to avoid excessive hip flexion.
2. Family education is important to avoid skin complications.

10 Cross-References

- [Femoral Shaft Fracture: Spica Cast](#)
- [Pathologic Femoral Shaft Fracture](#)

References and Suggested Reading

- Flynn JM, Schwend RM (2004) Management of pediatric femoral shaft fractures. *J Am Acad Orthop Surg* 12(5):347–359
- Treatment of pediatric diaphyseal femur fracture. Evidence based clinical practice guideline. Copy right 2015 by the American Academy of Orthopaedic Surgeons
- Wood JN et al (2014) Prevalence of abuse among young children with femur fractures: a systematic review. *BMC Pediatr* 14:169

Femoral Shaft Fracture: Spica Cast

Michael G. Saper

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Abstract

A 2-year-old girl sustained a closed, displaced fracture of the right femoral shaft. The oblique fracture pattern in the diaphysis and 1.5 cm of shortening made the fracture amenable to traditional closed treatment methods. A closed reduction of the right femoral shaft fracture was performed followed by hip spica cast application. This technique has been shown to be effective in children younger than 6 years with less than 2 cm of shortening. The fracture healed without complications or subsequent manipulation in 1 month. By 9 months, the fracture had remodeled to near anatomic alignment with no significant leg length discrepancy.

1 Brief Clinical History

A 2-year-old girl sustained a closed, displaced fracture of the right femoral shaft after an unwitnessed fall from her crib. Her fracture was temporarily immobilized in the emergency department. She was taken to the operating room the following morning for definitive treatment. Due to her age, the oblique fracture pattern in the diaphysis, and 1.5 cm of shortening, it was decided to manage the injury by performing a closed reduction followed by hip spica cast application.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

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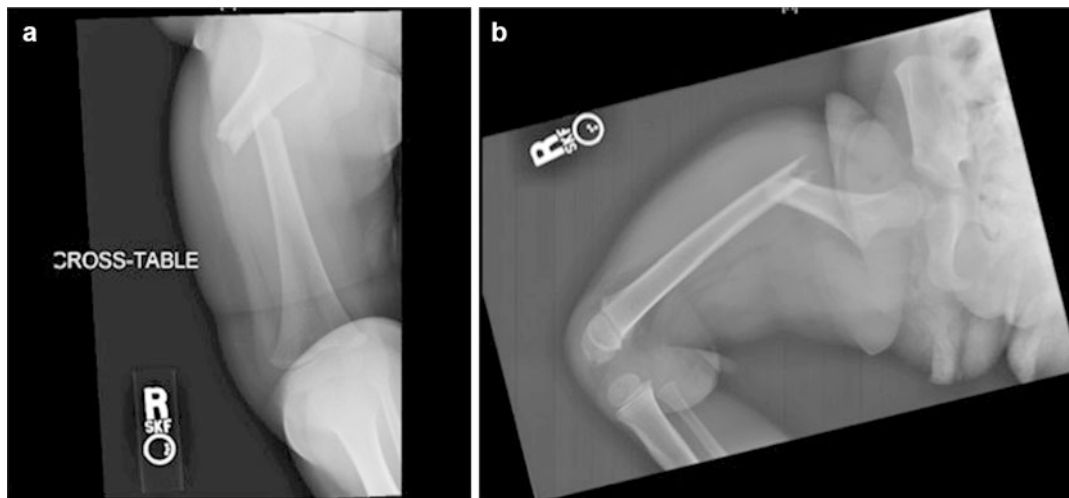


Fig. 1 AP (a) and lateral (b) views demonstrate the short oblique fracture of the right femoral diaphysis with >100% medial displacement. There are 60° procurvatum and 50° varus deformities of the fracture with 1.5 cm of shortening

3 Preoperative Problem List

1. Closed femoral shaft fracture
2. Choice of fracture treatment/fixation
3. Age less than 6 years old
4. 1.5 cm of shortening

4 Treatment Strategy

A complete history and physical was performed to identify any signs of child abuse. The femoral shaft fracture was managed by temporary immobilization with a well-padded J-splint in the emergency department. A posterior long leg splint could also be utilized but carries an increased risk of pressure ulcers at the heel with prolonged immobilization. As this was a low-energy fracture with initial shortening less than 2 cm, prolonged traction (e.g., skeletal or Buck's traction) was not necessary. The fracture had significant displacement medially with varus and procurvatum deformities due to the deforming muscular forces. The resultant deformities were outside of acceptable tolerances of closed treatment without manipulation of the fracture. Closed reduction and 1½-leg hip spica cast application was felt to be the best option for this injury. To offset the deforming forces and maintain the fracture in acceptable alignment, the knee was flexed 60°, and the hip was flexed 60°, abducted 30°, and externally rotated 15°. Greater degrees

of flexion and abduction may be required for more proximal fractures. A valgus mold at the fracture site was applied.

5 Basic Principles

- Be aware of indicators of child abuse.
- Initial shortening of 2–3 cm is acceptable because of anticipated overgrowth.
- A small towel roll is placed under the stockinette at the abdomen extending to the nipple line. Once removed, the remaining space allows for normal respiratory excursion.
- Hips are flexed 60–90° and abducted 20–30°.
- A single-leg walking spica cast can be applied in low-energy fractures with the knee flexed 50°, the hip flexed 45°, abducted 30°, and externally rotated 15°. Advantages include increased mobility and independence, easier access to the perineal area. They also allow children to fit into car seats easier and to wear normal clothes. Outcomes, including alignment and complications, are similar to 1½ and double-leg hip spica casting.
- Depending of the age of the patient and stability of the fracture, weekly films are obtained to monitor for loss of reduction for the first 2–3 weeks.
- A special car seat is needed for transport.
- Acceptable deformity for children aged 2–6 years includes:

- Less than 20° of sagittal plane deformity
- Less than 15° of coronal plane deformity
- Less than 10° of rotational deformity
- Less than 2 cm of shortening

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

- A firm understanding of the deforming muscular forces on the fracture is required to perform the appropriate reduction.
- Extra padding should be placed on the bony prominences and around all edges of the cast.
- A long leg cast is applied on the injured limb first, and then the patient is transferred to the spica table. When applying the cast in this order, it is critical to avoid placing traction and compression at the popliteal fossa.
- The upper portion of the cast should stop 1–2 inches below the nipple line. This will ensure that the cast does not impinge into the axillae when the child is in an upright position.
- Reinforcing strips of fiberglass should be placed near the hip joint for added stability.

- If needed, cast wedges can be utilized to correct up to 10° of deformity.
- The duration of casting is determined by radiographic evidence of healing on subsequent films. However, a general rule of thumb for is the age of the patient +3 weeks.

8 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

9 Avoiding and Managing Problems

- A valgus mold at the fracture site is important to resist the common varus deformity associated with mid-shaft fractures.
- Sufficient hip abduction is necessary for perineal care. However, excessive hip abduction >30° can cause increased pressure on the femoral head with resultant avascular necrosis.
- Avoid applying a short leg cast first and then applying traction with the knee at 90° of flexion. This increases the risk of compartment syndrome.

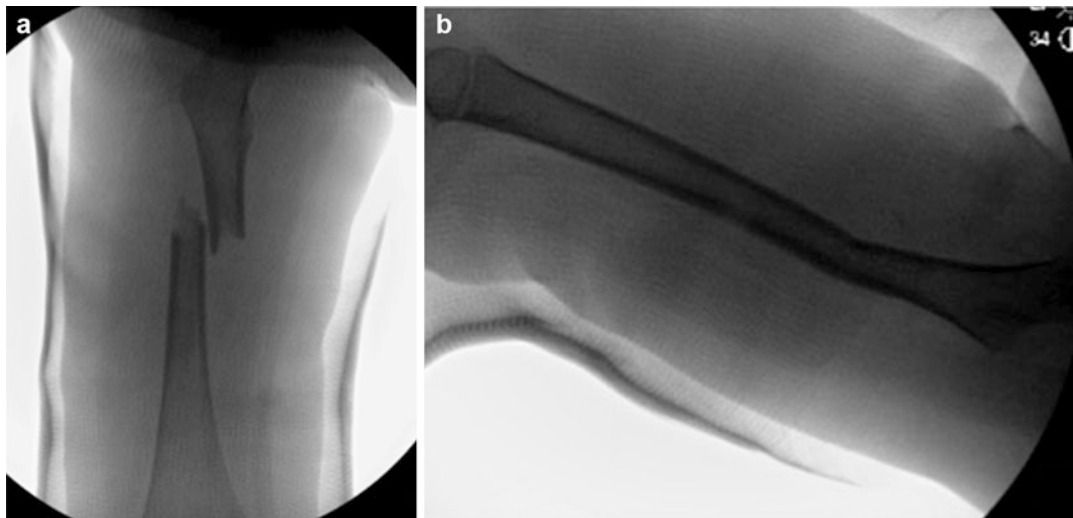


Fig. 2 Following closed reduction and application of the hip spica cast, AP (a) and lateral (b) views demonstrate the short oblique fracture of the right femoral diaphysis with > 100% medial displacement and 1.5 cm of shortening. The knee was flexed 60°. The hip was flexed 60°, abducted

30°, and externally rotated 15°. A valgus mold at the fracture site was applied. The procurvatum and varus deformities have been corrected to neutral

Fig. 3 AP (a) and lateral (b) radiographs out of the cast at 1 month show acceptable alignment of the femur with abundant callus formation. The original procurvatum and varus deformities have not recurred

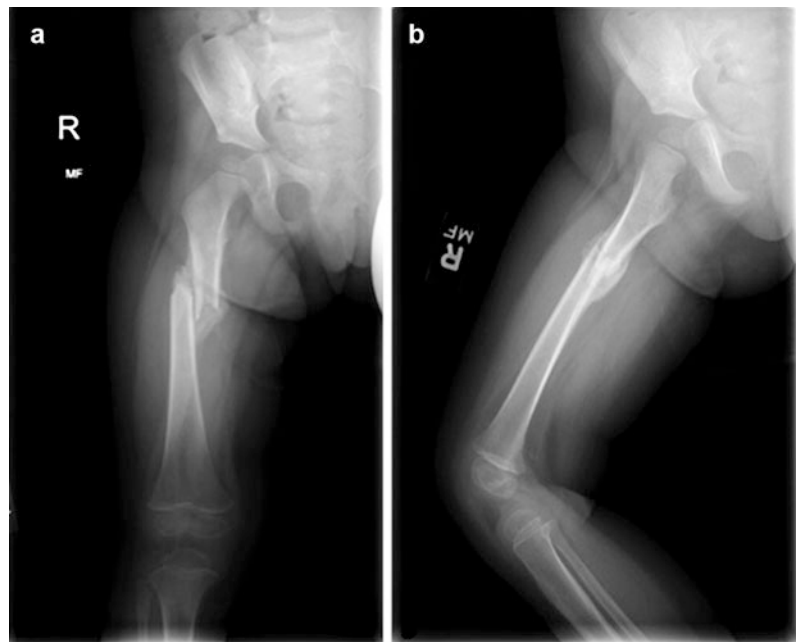


Fig. 4 A standing AP legs radiograph at 9 months follow-up shows near anatomic remodeling of the right femoral diaphysis. There is no significant leg length inequality. A clinical exam alone may also be utilized to evaluate alignment and length at follow-up

- For distal third fractures, knee flexion relaxes the deforming forces of the gastrocnemius to avoid a recurvatum deformity.

10 Cross-References

► Femoral Shaft Fracture: Plating

References and Suggested Readings

- Anglen JO, Choi L (2005) Treatment options in pediatric femoral shaft fractures. *J Orthop Trauma* 19(10):724–733
- Ferguson J, Nicol RO (2000) Early spica treatment of pediatric femoral shaft fractures. *J Pediatr Orthop* 20:189–192
- Flynn JM, Schwend RM (2004) Management of pediatric femoral shaft fractures. *J Am Acad Orthop Surg* 12(5):347–359
- Flynn JM, Garner MR, Jones KJ, D'Italia J, Davidson RS, Ganley TJ, Horn BD, Spiegel D, Wells L (2011) The treatment of low-energy femoral shaft fractures: a prospective study comparing the “walking spica” with the traditional spica cast. *J Bone Joint Surg Am* 93(23):2196–2202
- Large TM, Frick SL (2003) Compartment syndrome of the leg after treatment of a femoral fracture with an early sitting spica cast: a report of two cases. *J Bone Joint Surg Am* 85:2207–2210

Femoral Shaft Fracture: Plating

Michael G. Saper

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Abstract

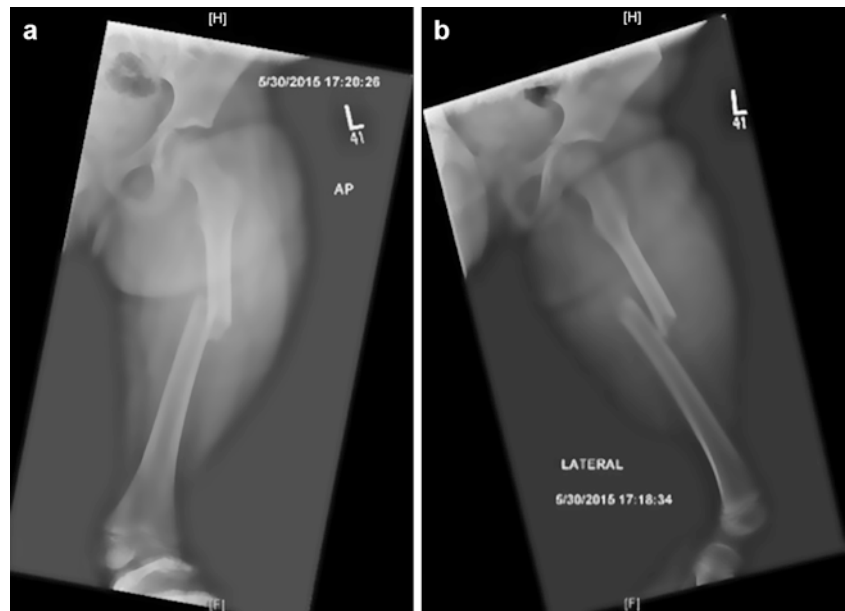
A 6-year-old girl sustained a closed, displaced, short oblique fracture of the left femoral shaft with shortening and mild comminution. The fracture characteristics and age of the patient made the fracture not amenable to traditional closed treatment methods. A closed reduction of the left femoral shaft fracture was performed followed by submuscular plating. This technique has been shown to be effective in children and older than 5 years. The fracture healed without complications. By 9 months, the femur exhibited complete remodeling.

1 Brief Clinical History

A 6-year-old girl sustained a closed, displaced fracture of the left femoral shaft after an 8-ft fall off of playground equipment. Her fracture was temporarily immobilized in the emergency department with a long leg splint. She was taken to the operating room the following morning for definitive treatment. Due to her age and fracture pattern, it was decided to manage the injury by performing a closed reduction followed by submuscular plating.

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Fig. 1 AP (a) and lateral (b) views demonstrate the short oblique fracture of the left femoral diaphysis with 100% medial displacement. The fracture was shortened and angulated into varus



2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Closed fracture of the mid-femoral diaphysis
2. Choice of fracture treatment/fixation
3. Age older than 5 years
4. Short oblique fracture pattern
5. Mild comminution
6. Healthy non-osteopenic bone

4 Treatment Strategy

The femoral shaft fracture had significant displacement medially with shortening and varus deformities due to the deforming muscular forces. The fracture was managed by temporary immobilization with a well-padded J-splint which avoids contact with the heel in the emergency department. A posterior long leg splint could also be utilized but carries an increased risk of pressure ulcers at the heel with prolonged immobilization. As early submuscular plating was deemed appropriate for this 6-year-old patient, prolonged traction (e.g., skeletal or Buck's traction) was not necessary. A 3.5-mm low contact-dynamic compression plate (LC-DCP) was felt to be the best option for the size of this patient's femur. The plate was contoured and placed with minimally invasive techniques above the periosteum. It

was secured with four non-locking screws proximal and three distal to the fracture.

5 Basic Principles

- Provisional reduction to restore length and rotation is obtained on a fracture table with boot traction.
- A narrow 4.5-mm LC-DCP is typically used, but a 3.5-mm plate can be chosen for smaller patients.
- The plate length is chosen based on the location of the fracture, spanning from below the trochanteric apophysis to the above distal femoral physis. If possible, the length should allow for six holes above and below the fracture. The plate is contoured to match the lateral aspect of the femur.
- The plate is placed submuscularly and over the lateral periosteum. It can be placed through a small (4–7 cm) distal or proximal incision.
- The “perfect circle” technique is used for percutaneous screw placement. The first screw reduces the femur to the precontoured plate.
- Optimally, 3 screws are placed proximal and 3 screws distal to the fracture. In comminuted or long oblique unstable fracture patterns, screw placement should follow the principles of external fixation.
- Hip spica casting is usually unnecessary as fixation is adequate. A soft dressing and knee immobilizer are applied postoperatively for comfort.
- Patients are made toe-touch weight bearing until early fracture callus is seen on postoperative radiographs, typically 6–8 weeks. Full activity is typically resumed at 10–12 weeks.



Fig. 2 Following closed reduction and submuscular plating, AP and lateral views demonstrate anatomic alignment of the short oblique fracture of the left femoral diaphysis

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

- Locking plates can be used in cases of osteopenic bone or in fracture patterns that limit the available room for screws proximally and/or distally.
- The plate is placed on the anterior thigh to shadow the lateral aspect of the femur to confirm the length and contour.
- Developing a submuscular plane is easier with a distal incision and retrograde plate insertion.
- With the fracture reduced and the plate position conformed with fluoroscopy, the plate is provisionally secured with K-wires through the most proximal and distal screw holes.
- In unstable fracture patterns, the screws should be spaced as far apart as possible.

8 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

9 Avoiding and Managing Problems

- Over- or undercontouring the plate can lead to malalignment of the fracture.
- Plate position should be confirmed intraoperatively with biplanar fluoroscopy prior to screw placement.
- Confirm appropriate rotational alignment of the leg prior to securing the plate.
- When placing screws percutaneously, tie a nonabsorbable suture around the screw head to prevent it from being lost in the soft tissue.
- Placement of the incision between two adjacent screw holes allows two screws to be placed through one percutaneous incision.

Fig. 3 Postoperative AP (a) and lateral (b) radiographs at 10 weeks show the completely healed mid-shaft fracture with abundant callus formation and periosteal remodeling

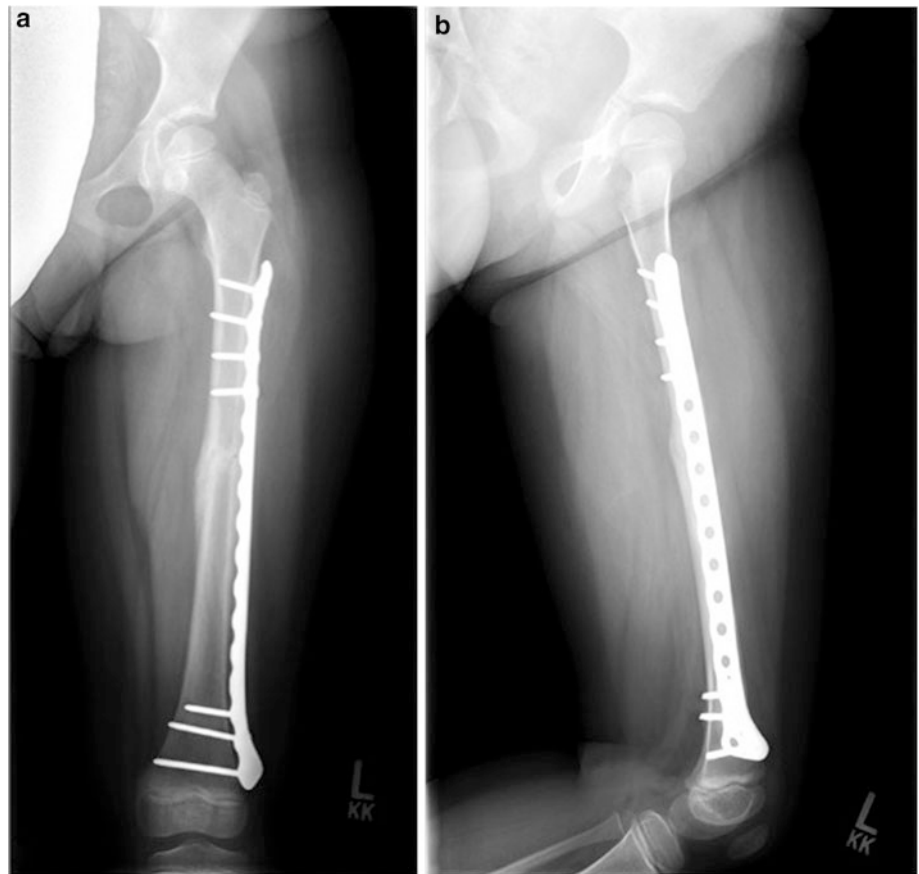
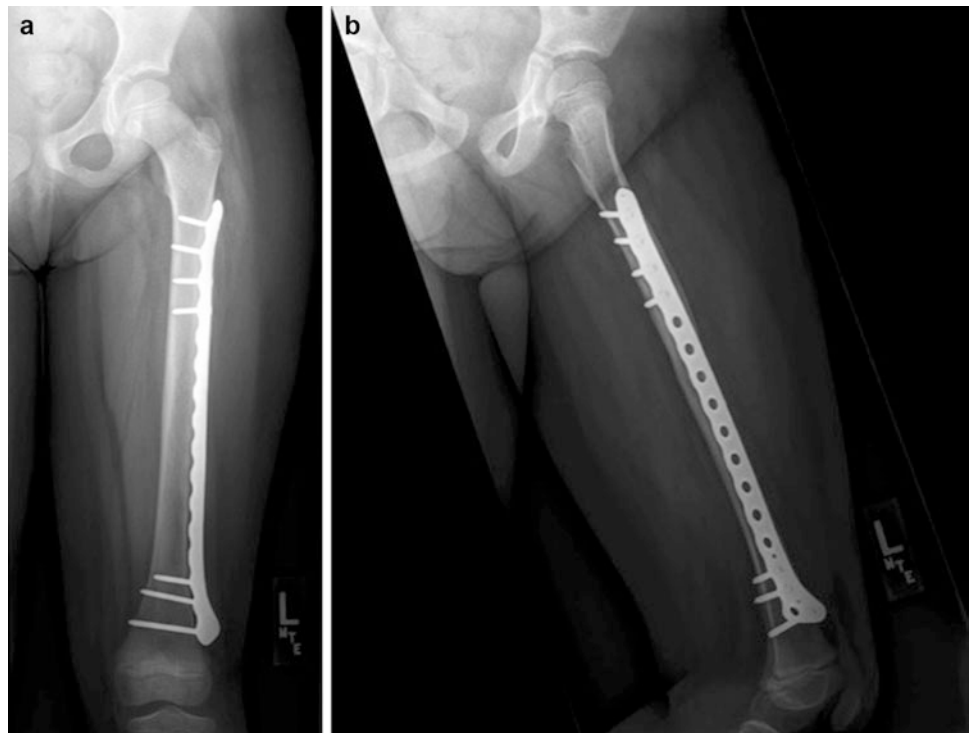


Fig. 4 Postoperative AP (a) and lateral (b) radiographs at 9-month follow-up show anatomic remodeling of the left femoral diaphysis



- Plate removal is optional and based on the surgeon and family's preference. However, due to bone overgrowth, removal should be performed at 6–12 months. If the plate is removed, limit sports and high-risk activities for 6 weeks to avoid refracture.

10 Cross-References

- [Comminuted Femoral Fracture Treated with Locked Enders Nails](#)
- [Femoral Shaft Fracture: Flexible Intramedullary Nails](#)
- [Femoral Shaft Fracture: Spica Cast](#)

References and Suggested Readings

- Abdelgawad AA, Sieg RN, Laughlin MD, Shunia J, Kanlic EM (2013) Submuscular bridge plating for complex pediatric femur fractures is reliable. *Clin Orthop Relat Res* 471(9):2797–2807
- Anglen JO, Choi L (2005) Treatment options in pediatric femoral shaft fractures. *J Orthop Trauma* 19(10):724–733
- Flynn JM, Schwend RM (2004) Management of pediatric femoral shaft fractures. *J Am Acad Orthop Surg* 12(5):347–359
- Hedquist DJ, Sink EL (2004) Technical aspects of bridge plating for pediatric femur fractures. *J Orthop Trauma* 19:276–279
- Li Y, Hedquist DJ (2012) Submuscular plating of pediatric femur fracture. *J Am Acad Orthop Surg* 20(9):596–603

Femoral Shaft Fracture: Flexible Intramedullary Nails

Albert Pendleton

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Abstract

A 6-year-old female sustained a right transverse mid-shaft femur fracture after being hit by a golf cart. Due to her skeletal immaturity and the transverse fracture pattern, flexible intramedullary nailing was chosen to stabilize the fracture. Flexible intramedullary nailing is ideal for patients who are too large for immobilization alone, but are skeletally immature, where drilling through the greater trochanteric apophysis would risk injury to the blood supply of the femoral head (< age 10). Flexible intramedullary nails can be considered in length-stable fracture patterns in patients less than 100 lb (45 kg) with open growth plates. Postoperatively, patients can be managed with a knee immobilizer or no immobilization depending on the stability of fracture fixation. The knee immobilizer can be removed to allow early range of

motion of the hip and knee. Hardware removal is often recommended, but it is not required.

1 Brief Clinical History

A 6-year-old female sustained a closed right transverse femur fracture after a golf cart accident. The golf cart flipped and pinned her leg underneath it. She was placed in a traction splint and transferred to our hospital. The rest of the trauma evaluation was negative. She was taken to the operating room that evening for flexible intramedullary nailing.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1a, b.

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Fig. 1 AP (a) and lateral (b) views demonstrate a transverse fracture of the femur shaft without shortening or comminution at the junction of the middle and distal thirds



3 Preoperative Problem List

1. Transverse femoral fracture, length stable
2. Open greater trochanteric apophysis and open distal femoral growth plate
3. Choice of fracture fixation

4 Treatment Strategy

There are many treatment options for this fracture including spica casting, flexible intramedullary nailing, external fixation, or submuscular plating. Spica casting is challenging from a patient and family perspective given the age and size of the patient, and the risk of fracture displacement in the cast. External fixation is an option as well, but would require pin site care and the risk of pin site infection. Submuscular plating could be performed, but is more invasive and is not necessary in a length-stable fracture pattern. Consequently, flexible nailing was chosen given its minimal invasive nature and ability to stabilize the fracture with postoperative immobilization.

5 Basic Principles

1. Flexible nails allow a minimally invasive approach to stabilize the fracture without disrupting the fracture site.
2. Appropriate bending of the nails will increase fracture stability in both planes. However, since the fracture is not at the isthmus, some degree of fracture motion will occur after stabilization of the fracture.

6 Images During Treatment

See Fig. 2a–f.

7 Technical Pearls

1. Patient positioning can make fracture reduction much easier. In this case, the patient was placed supine on the radiolucent table, which allows ease of obtaining AP and lateral x-rays by rotation of the leg. However, if the fracture has significant shortening, a fracture table or traction bow can be used to help hold the fracture out to length during internal fixation. Traction can hold the fracture reduction via ligamentotaxis, especially if the surgeon does not have an assistant.
2. Ensure you can easily obtain AP and lateral views of the hip prior to prepping and draping. If using a fracture table, you can reduce the fracture prior to prepping and draping. The contralateral leg can be placed in the lithotomy position or scissored downward in order to obtain a good lateral of the hip, which is essential to monitor during final nail placement.
3. If the fracture is resistant to reduction, the use of a bump or crutch under the thigh can help translate the distal fragment anteriorly. Also, small percutaneous incisions near the fracture site and use of a ball-spike pusher can aid fracture reduction.
4. The incision starts just proximal to the growth plate and progresses proximal. The soft tissue exposure includes incising the IT band laterally and VMO fascia medially

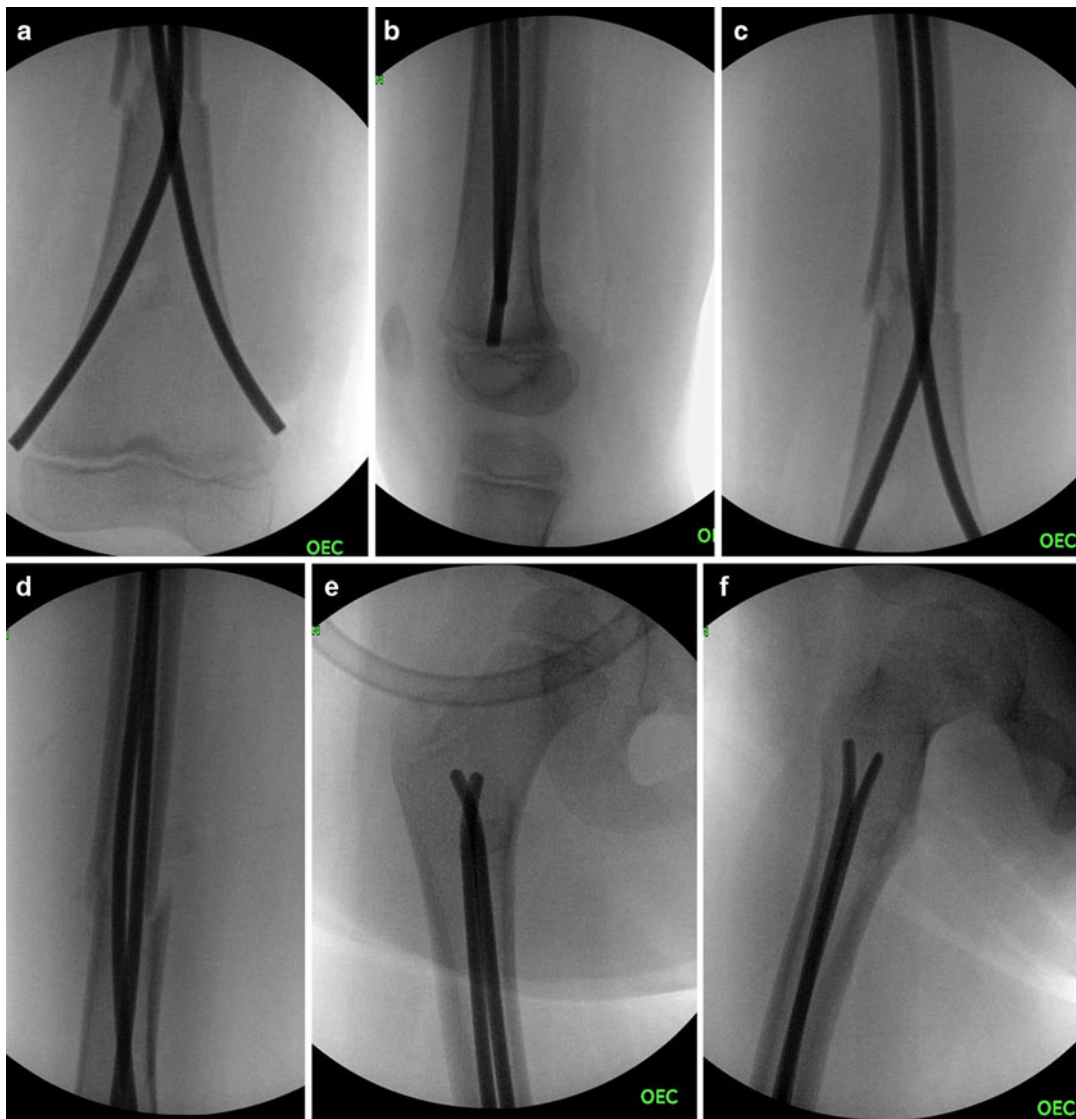


Fig. 2 (a–f) Fluoroscopic images of flexible nail placement within the shaft of the femur bone. Note the retrograde entry point into the femur is 3 cm proximal to the growth plate

using the scalpel. The incision needs to be extended distally because once the nail insertion process starts, the hardware projects in a distal direction. The nail will impinge on the skin if the incision is made too proximally.

5. The starting hole is generally 2–3 cm proximal to the distal femoral physis. Start the drill perpendicular to the cortex, create the pilot hole, and bring your hand distally to angle the hole up the canal. Do not perforate the far cortex.
6. The ideal nail size is 40% the size of the canal which can be measured preoperatively or by lying the nails over the top of the bone intraoperatively at the isthmus. The two flexible nails should fill 80% of the width of the canal and should both be the same size.
7. Pre-bend the nail with a gentle curve to ease nail entry into the medullary canal. Do not perforate the far cortex with the nail as this makes it more challenging to insert the nail once a breach has occurred. The nail should be advanced by the hand as much as possible. Rotating the nail back and forth during the insertion process helps to prevent the tip of the nail from burrowing a hole into the far cortex.
8. Advance both nails to the fracture site, and then advance both nails across the fracture site sequentially in 1 cm increments to prevent fracture displacement. The nail can also be bent further using the rod impactor once across the fracture site to increase stability.
9. The nails should be inserted short of their final position because they will need to be advanced with a bone tamp

for approximately the final centimeter. The goal should be to aim toward the greater trochanteric apophysis with the lateral nail. The medial nail should curve toward the femoral neck. In the lateral view, the tips of the nails should be pointing in opposite directions.

10. To cut the nails, bend them away from the bone in a proximal direction. This will allow the nail cutter to cut the exposed portion of the nail as short as possible. A straight or angled bone tamp should then be used to advance the nail the final 1 cm. Take care to leave a
11. A knee immobilizer can be used postoperatively. This will allow the soft tissues to rest, will assist with pain control, and will keep the patient from advancing their activities too quickly. It can be removed to allow early range of motion of the knee.

Fig. 3 Final reduction AP (a) and lateral (b) radiographs. The medial translation of the distal fracture fragment is within acceptable limits. Also, note the final position of the intramedullary rods proximally and distally

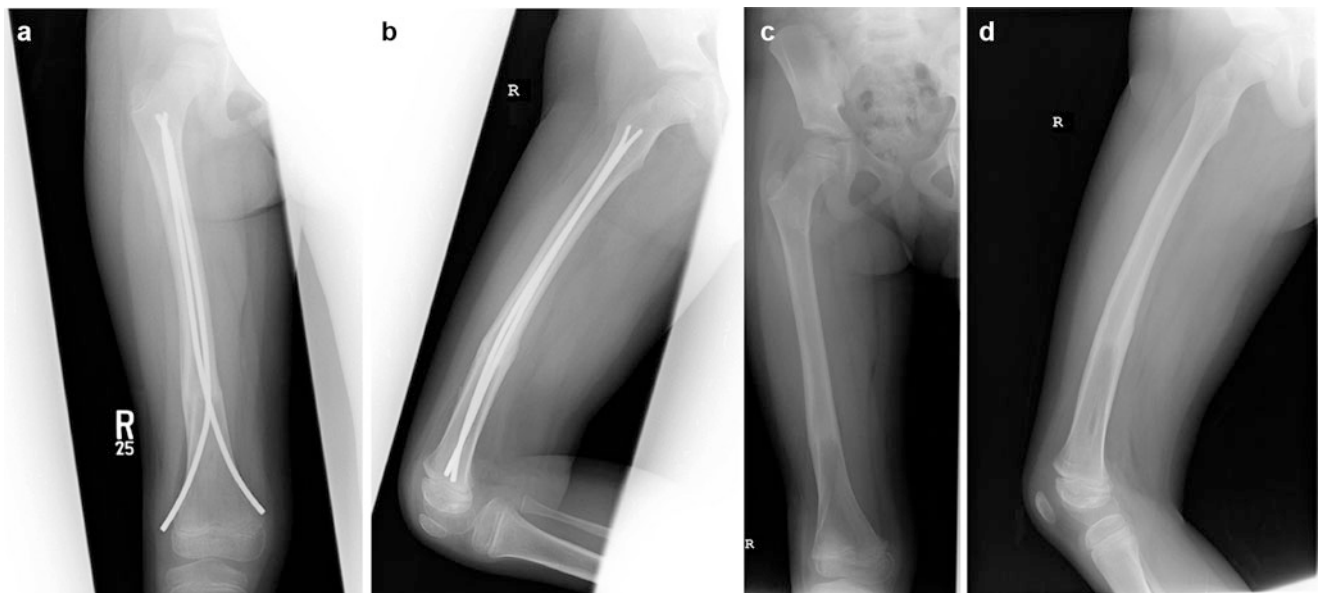


Fig. 4 (a) and (b) are AP and lateral radiographs of the fracture at 3 months postoperatively. (c) and (d) are AP and lateral radiographs after hardware removal at 6 months

8 Outcome Clinical Photos and Radiographs

See Figs. 3a, b and 4a–d.

9 Avoiding and Managing Problems

1. Use patient positioning to aid in fracture reduction. Having the fracture reduced facilitates the nail insertion process.
2. Reduction instruments, such as the “F” tool, can be used to assist in obtaining an adequate closed reduction.
3. Be careful not to perforate the far cortex during canal entry or nail insertion. If this occurs, remove the nail and place a more aggressive bend on the tip of the nail. This will help to prevent the nail from heading back to the same spot on the far cortex. If using stainless steel flexible rods, switching to a titanium rod may also help to avoid the perforation in the cortex.
4. Use the tips of the rods to guide passage into the proximal fragment. For example, if the proximal piece is displaced laterally, then rotate the rod tip to face laterally. Once the tip engages the proximal piece, the rod tip can be rotated 180° in the opposite direction to pull the fragment into better alignment.
5. Avoid making multiple false passes with the flexible nails. Nail passes that miss the proximal fragment will cause increased injury to the soft tissues. Do not hesitate to open the fracture site through a small incision and reduce the fracture with an elevator, a ball-spike pusher, or your finger.
6. If fracture displacement occurs while passing the nail across the fracture site, try advancing the other nail first and advance the nails sequentially in smaller increments.
7. Once nails are seated, check how far proximal you can cut the nail versus where you want to cut the nail. Mark the location where you want the nail to end, back the nail out, cut, and readvance. This decreases the chances of either advancing the nail across the proximal femoral apophysis or leaving the nail too proud distally or near the distal femoral growth plate.

10 Cross-References

- [Comminuted Femoral Fracture Treated with Locked Enders Nails](#)
- [Humeral Shaft Fracture: Flexible Intramedullary Fixation](#)
- [Midshaft Both Bone Forearm Fracture: Intramedullary Rod Fixation](#)
- [Tibial Shaft Fracture: Flexible Nails](#)

References and Suggested Readings

- Barry M, Paterson JMH (2004) Flexible intramedullary nails for fractures in children. *JBJS (Br)* 86-B:947–953
- Gholive A, Flynn JM (2011) Femur fracture: flexible intramedullary nailing. In: Kocher M, Millis M (eds) *Operative techniques: pediatric orthopedic surgery*, 1st edn. Philadelphia, pp 241–252
- Reynolds RAK, Legakis JE, Thomas R, Slongo TF, Hunter JB, Clavert JM (2012) Intramedullary nails for pediatric diaphyseal femur fractures in older, heavier children: early results. *J Child Orthop* 6(3):181–188

Femur Fracture: Alternatives to Spica Casting for Fractures in Patients Under Age 6

Daniel G. Hoernschemeyer and Madeline E. Robertson

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Abstract

A 4-year-old male sustained a left femoral shaft fracture after falling from a chair. While pediatric femoral shaft fractures may be treated with spica casting or flexible nailing, the 2.5 cm femoral shortening along with the patient's age suggested alternatives to spica casting be considered. Using retrograde techniques, the fracture was reduced and two 3-mm titanium flexible nails were placed in a retrograde fashion. The fracture subsequently healed and the hardware was removed 1 year after placement.

1 Brief Clinical History

A 4-year-old male presented to the emergency department with severe thigh pain and swelling after falling from a barstool. He was found to have sustained a left spiral femoral fracture. The patient was admitted, placed in skin traction, and received pain control overnight. Due to the fact that the patient had a significant amount of overlap, was potty-trained, and had a social history requiring day care, it was decided to proceed with flexible nailing as opposed to spica casting. The following morning, the patient was brought to the operating room where he was placed under general anesthesia and given a paralytic to aid in the reduction. Two 3-mm Titanium elastic nails were placed in a retrograde fashion across the fracture site. After confirming the alignment with C-arm imaging, the flexible nails were cut to the appropriate length and a knee immobilizer was placed.

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2 Preoperative Clinical Photos and Radiographs

See Fig. 1

3 Preoperative Problem List

1. Four-year-old male with a left spiral femoral shaft fracture
2. Two and a half centimeters of femoral shortening at the fracture site
3. Potty-trained child
4. Child attending day care
5. Deciding the treatment strategy between flexible nailing and spica casting

4 Treatment Strategy

The displaced femoral shaft fracture was initially managed in the ED with conscious sedation and placement of the skin traction. The patient was admitted to the pediatric floor for observation and elevation of the extremity along with pain control. The following morning he was brought to the operating room for placement of flexible nails. The child was placed on a radiolucent table with a bump below the left hip and leg. Our goal was to obtain three-point fixation along with rotational alignment of the extremity. After prepping and draping of the left lower extremity, incisions were made over the medial and lateral aspects of the distal femoral metaphysis. Two awls were used to enter the intramedullary canal, allowing us to be more precise with the starting point. The entry into the bone was then overdrilled with a 4.5 mm drill. Two 3-mm

Titanium elastic nails were then passed up the intramedullary canal to the level of the fracture site. The fracture was reduced with mild traction and the F-tool, followed by passage of the two nails together across the fracture site. The flexible nails were cut to the appropriate length and tamped down to the outer distal femoral cortex. Intraoperative imaging confirmed anatomic reduction and layered closure began. The patient was placed in a knee immobilizer and was instructed to weight bear as tolerated. He returned to full weight-bearing and normal activities at 6 weeks and underwent hardware removal at 1 year following the initial surgery.

When evaluating pediatric femoral shaft fractures it is important to consider the following:

1. Age of the patient: Traditionally, patients younger than 6-years-old have been treated with spica casting; however, some literature supports treatment using flexible nailing at a young age.
2. Amount of femoral shortening: When the femoral shortening measures 2.5 cm or more, the risk of maintaining overlap during healing and developing a leg length discrepancy increases.
3. Weight of patient: Obesity rates in children continue to rise. Obese children in spica casts are more difficult to lift and transport safely. Additionally, management of the reduction may be harder to maintain.
4. Toileting: Toileting habits should be considered when evaluating pediatric femur fracture treatment strategies. If a child is potty-training or is already using the toilet, good toileting habits are easier to maintain with flexible nailing than with spica casting.
5. Social situation: Spica casting requires significant changes to family dynamics during treatment. In single-parent

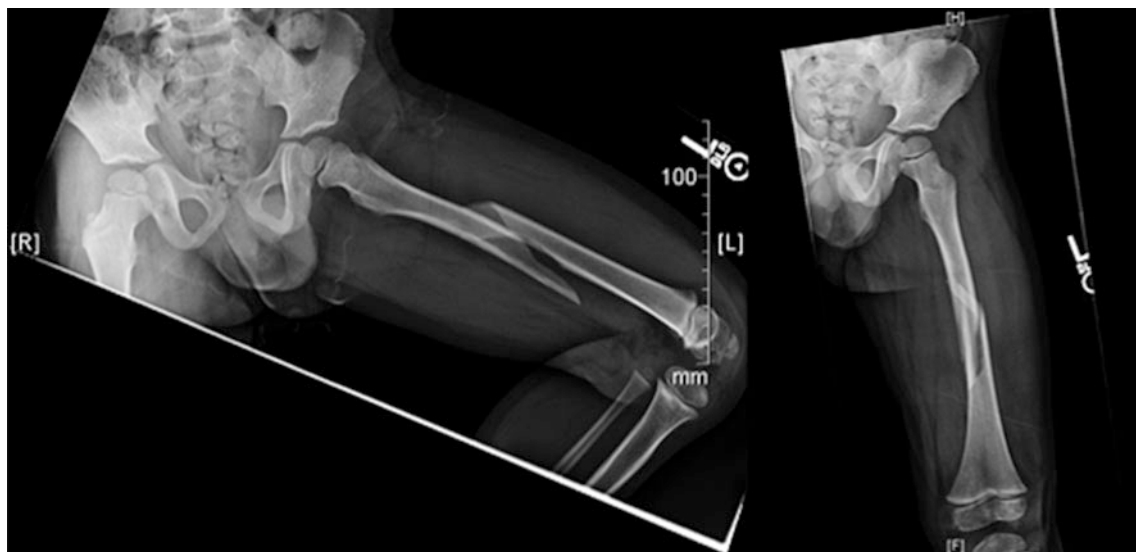


Fig. 1 Left spiral comminuted femur fracture with 2.5 cm of shortening

families, and families with two-working parents, care-givers may be unable to have extended time off of work to assist the child with spica cast needs. These needs may also prevent children from being permitted to attend daycare.

6. Implants are typically removed between 9 and 12 months postoperatively.

5 Basic Principles

1. Stabilize the femur fracture with internal fixation using 3 mm flexible nails, avoiding the need for spica casting
2. Reduction of the fracture using indirect methods – traction/F-tool
3. Allow for early mobilization to assist with toileting and return to schooling/day care

6 Images During Treatment

See Figs. 2 and 3

Figure 3 shows AP views of the femur at 3 weeks, 11 weeks, and 11 months from surgery (left to right). X-rays show callus formation with complete healing and maintained alignment.

Fig. 2 (a) The distal femoral physis is identified prior to making incisions. (b) The IM canal is entered just proximal to the physis using an awl. (c and d) demonstrate AP and lateral views confirming the fracture reduction with appropriate length of the flexible nails

7 Technical Pearls

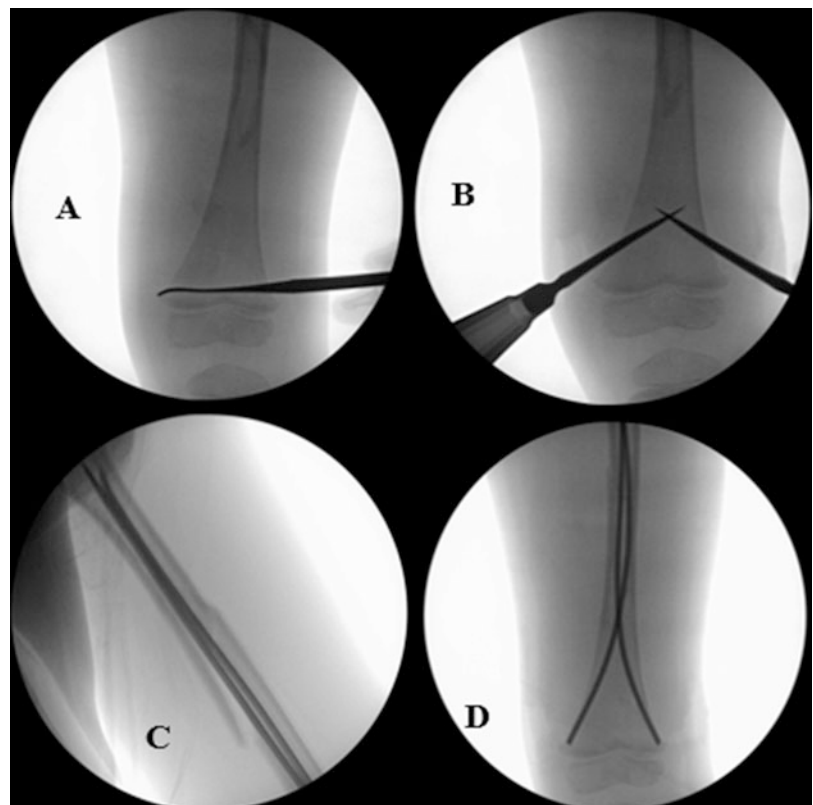
1. American Academy of Orthopedic Surgeons (AAOS) guidelines for femur fractures in children age 2–6 years recommend early spica casting; however, some authors recommend intramedullary stabilization
2. Both treatment options have proven to be effective with no difference in postoperative; however, intramedullary nailing has a significantly lower socioeconomic impact on the family
3. Treatment decisions for each patient should be individualized based on the family and should impact the surgeon's decision-making process

8 Outcome Clinical Photos and Radiographs

See Fig. 4

9 Avoiding and Managing Problems

1. Nail irritation at the entry site – nails should be cut so they lie flush with the metaphysis of the distal femur. Only 1–2 cm of the nail should be outside the cortical entry site
2. Nonunion, delayed union, malunion – be sure to check final fracture configuration determining that there is no



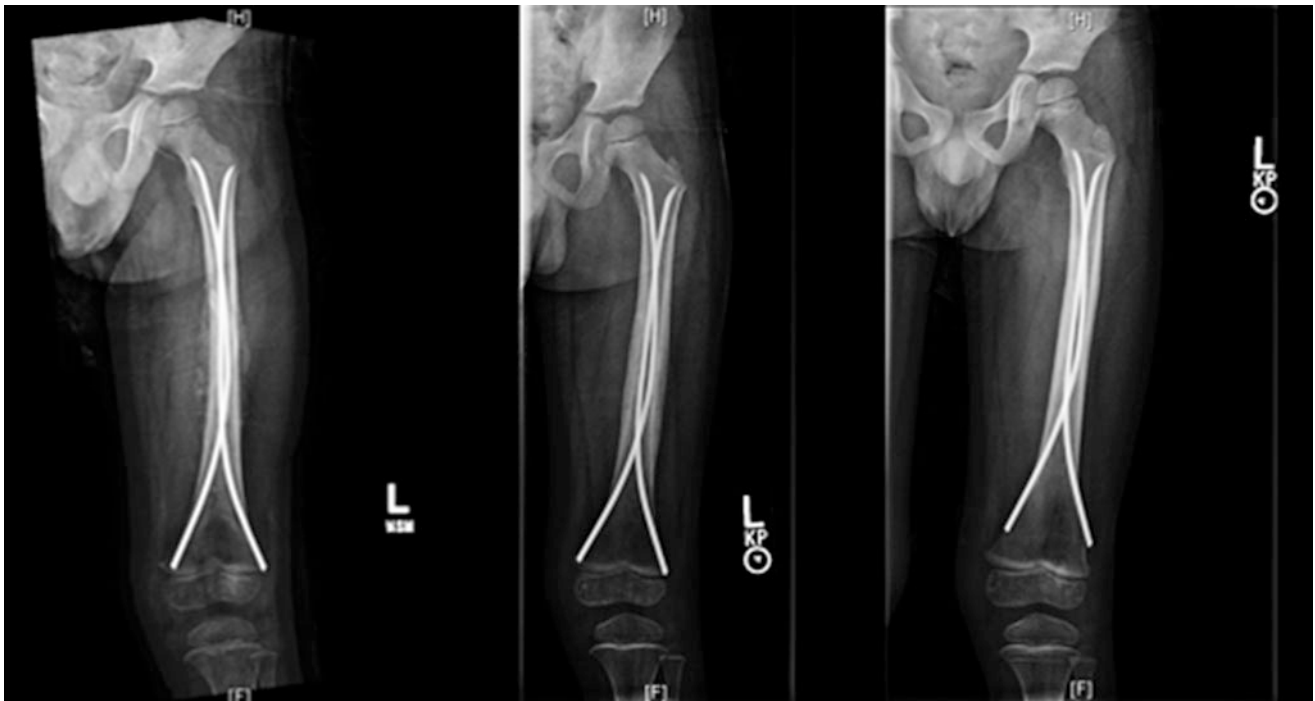


Fig. 3 shows AP left femur films from initial post-op, 12 weeks post-op, and 1 year post-op demonstrating interval healing of the fracture and placement of the flexible nails

Fig. 4 shows the well-healed fracture after removal of the intramedullary nails. The fracture has healed with proper alignment and shows no evidence of malunion



significant gap between the fracture fragments – along with rotational alignment of the extremity

3. Leg length discrepancy – assess rotational alignment of the extremity intraoperatively and follow post-op up for signs of femoral shortening and overgrowth
4. Difficult insertion or nail passage – anterograde method of insertion through the greater trochanter may be used for one or both nails
5. Recognizing that the spica cast requires modifications in a child's environment
6. Spica casting shifts care burden to the family
7. Children who are potty-trained, attending day care or school, obese, and single-parent families are not ideal for spica casting

10 Cross-References

- [Femoral Shaft Fracture: Flexible Intramedullary Nails](#)
- [Femoral Shaft Fracture: Spica Cast](#)

References and Suggested Reading

- Bopst L, Reinberg O, Lutz N (2007) Femur fracture in preschool children: experience with flexible intramedullary nailing in 72 children. *J Pediatr Orthop* 27(3):299–303
- Goodbody CM, Flynn JM (2016) Flexible intramedullary nailing of femoral shaft fractures. In: Flynn JM, Sankar WN, Wiesel SW

- (eds) Operative techniques in pediatric orthopaedic surgery, 2nd edn. Wolters Kluwer, Philadelphia, pp 197–201
- Herring JA (2008) Tachdjian's pediatric orthopaedics from the Texas Scottish rite hospital for children, 4th edn. Saunders Elsevier, Philadelphia, pp 2641–2647
- Kocher MS et al (2009) Treatment of pediatric diaphyseal femur fractures. *J Am Acad Orthop Surg* 17(11):718–725
- Shemshaki HR, Mousavi H, Salehi G, Eshaghi MA (2011) Titanium elastic nailing versus hip spica cast in treatment of femoral-shaft fractures in children. *J Orthop Traumatol* 3(1):45–48
- Simanovsky N, Porat S, Simanovsky N, Eylon S (2006) Close reduction and intramedullary flexible titanium nails fixation of femoral shaft fractures in children under 5 years of age. *J Pediatr Orthop B* 15(4): 293–297
- Song HR, Oh CW, Shin HD et al (2004) Treatment of femoral shaft fractures in young children: comparison between conservative treatment and retrograde flexible nailing. *J Pediatr Orthop B* 13:275–280

Comminuted Femoral Fracture Treated with Locked Enders Nails

Philip McClure and Anthony I. Riccio

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Abstract

Many fixation methods have been proposed for the surgical management of pediatric diaphyseal femur fractures. Implant selection is traditionally based upon the fracture pattern, fracture location, presence of comminution or segmental bone loss, and patient weight and age. In younger children, comminution and length stability of the fracture often dictate implant selection as well as the use of adjunctive postoperative cast immobilization to prevent shortening at the fracture site. Flexible intramedullary fixation is often considered the “gold standard” for treatment of femoral shaft fractures in children between the ages of 5 and 11 years. Nonetheless,

many surgeons prefer alternative methods of fixation when comminution is present due to concerns of shortening across the comminuted segment which can result in limb length inequality and partial nail extrusion with resultant knee pain due to hardware prominence. Because many flexible nails do not have distal interlocking capability to maintain fracture length, submuscular plating, open plating and external fixation are all viable options for restoration of femoral alignment and maintenance of length in comminuted fractures. This case highlights the use of locked flexible intramedullary stainless steel Enders nails (Smith & Nephew, Memphis, TN) for fixation of a comminuted femoral shaft fracture in a 9-year-old child.

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1 Brief Clinical History

A 9-year-old female sustained a twisting injury to her right lower extremity injury while jumping on a trampoline. She was unable to bear weight and immediate deformity about the thigh was noted. Clinical examination upon presentation

revealed normal motor, sensory, and vascular examinations with no evidence of injury remote to the right thigh. Radiographs demonstrated a comminuted femoral shaft fracture with a large anterior butterfly fragment.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

Right Comminuted Femoral Shaft Fracture.

4 Treatment Strategy

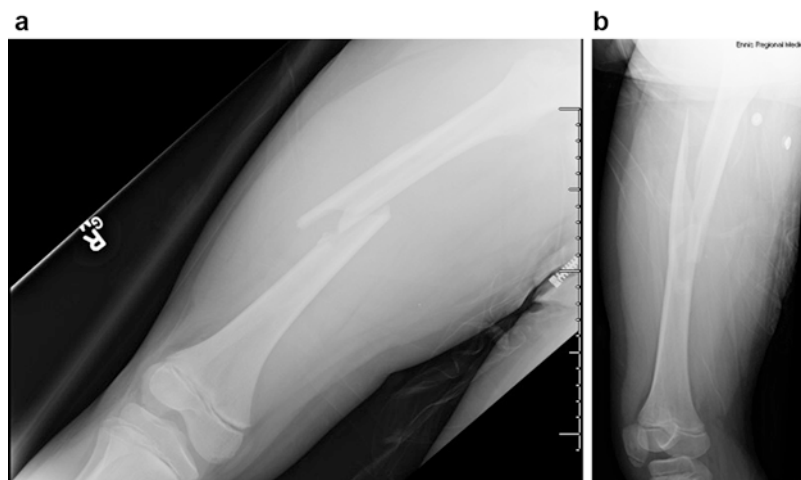
Management of this fracture entails accurate restoration of femoral length, rotation, and alignment. Fracture stabilization must be accomplished with an implant that prevents shortening across the comminuted segment in this length unstable fracture. In addition, one should select an implant that can be placed without violating the distal femoral physes. These goals are readily accomplished with retrograde locked stainless steel Ender flexible intramedullary fixation inserted on a flat top table. Nail diameter selection is selected based upon preoperative radiographic measurement of the femoral canal diameter with a goal of 80% canal fill between the two nails. Proper nail lengths are selected after which the nails are contoured to provide balanced fixation at the fracture site. Nails are introduced 1.5–2 cm proximal to the distal femoral physis through medial and lateral entry points and advanced to, but not across, the fracture site. The nails are then used as

handles to restore length and alignment. They are then sequentially advanced across the fracture site and into the dense metaphyseal bone of the proximal femur. The nails are seated flush along the distal femoral metaphysis. Once alignment, length, and rotation are confirmed fluoroscopically, the distal nail eyelets are filled with 2.7 mm fully threaded cortical screws. These distal interlocking screws confer length stability to the construct and prevent shortening at the fracture site. Rotational alignment is compared to the contralateral limb and rotational stability is assessed. If the fracture remains rotationally unstable following fixation, a single leg spica cast is applied to confer stability.

5 Basic Principles

Restoration and maintenance of proper femoral length and rotation are critical in comminuted femoral shaft fractures. Fluoroscopic imaging should be used to evaluate reduction in all planes. Rotation can be difficult to judge in comminuted fractures, and fluoroscopic imaging of the contralateral knee and proximal femur may be helpful in gaining an understanding of the patient's anatomic alignment. If any direct cortical apposition is available, the thickness of the cortices can provide further assurance that rotational alignment is reasonable, as the thickness of the cortex varies on each surface of the femur. Restoration of length is often based upon residual cortical apposition, but if this is absent, preoperative assessment of the length of the contralateral extremity is helpful. Length unstable fractures stabilized with flexible intramedullary nails can shorten across the fracture site if efforts are not taken to avoid this complication. As nails are often impacted into the dense bone of the proximal metaphysis, collapse across the fracture site often results in the nails extruding out the distal entry holes, becoming

Fig. 1 AP (a) and Lateral (b) femur radiographs demonstrate a midshaft long oblique fracture of the femoral diaphysis with a large anterior butterfly fragment



prominent and often creating pain by irritation of the medial and lateral thigh musculature. This can be avoided by the placement of distal interlocking screws in implants with eyelets to accommodate such screws. Alternatively, supplemental spica cast immobilization can assist in controlling length and rotation when distal interlocking is not possible or in cases when concerns for rotational instability persist after fixation has been achieved.

6 Images During Treatment

See Figs. 2, 3, 4, and 5.

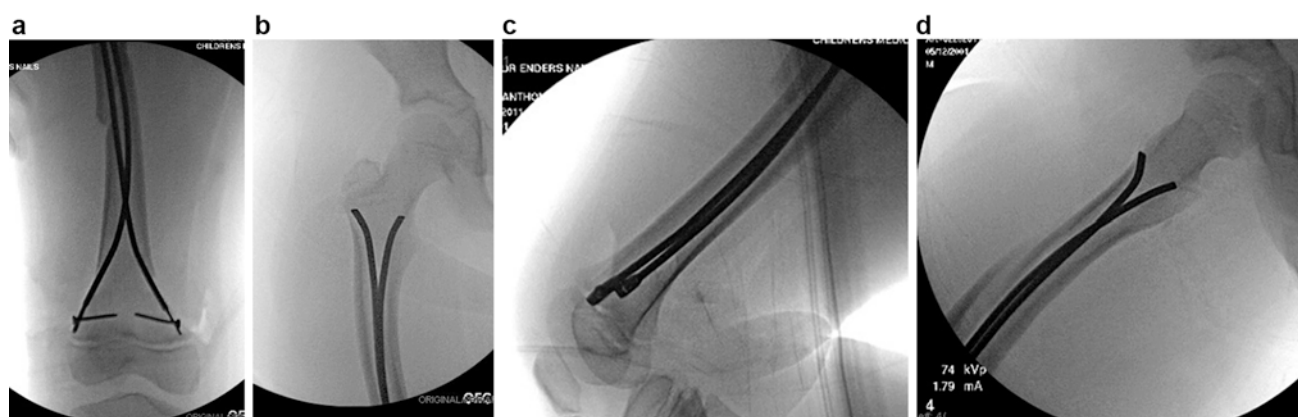


Fig. 2 Intraoperative fluoroscopic AP (a and b) and Lateral (c and d) imaging demonstrates adequate reduction in all planes and restoration of femoral length. Retrograde intramedullary stainless steel Enders nails are appropriately positioned and contoured to provide balanced fixation at the fracture site. The distal ends of both nails are proximal to the distal

7 Technical Pearls

Perform the surgery on a flat top table, as fracture table traction is rarely necessary for length restoration in these fractures. Determine nail length by fluoroscopic imaging with the nail lying over the femur after length has been restored by manual traction. The distal end of the nail should be approximately 2 cm proximal to the distal femoral physis and the proximal end just shy of the greater trochanter (lateral entry nail) or the base of the femoral neck (medial entry nail). Proper nail diameter is most easily determined by preoperative measurement of the femoral canal. Alternatively, the nail may be placed immediately lateral to the femur for fluoroscopic assessment of diameter. Placing the nail anterior to the

femoral physis to avoid pressure on the perichondral ring. 2.7 mm fully threaded cortical screws have been placed through the distal islets to prevent shortening. The proximal ends of the nails are firmly fixed through impaction into the dense metaphyseal bone of the proximal femur

Fig. 3 AP (a) and lateral (b) radiographs 2 weeks from surgery demonstrate maintenance of near anatomic alignment without evidence of shortening at the fracture site. The single leg spica cast was discontinued at this time to allow self-guided knee range of motion. Toe touch weight bearing was initiated

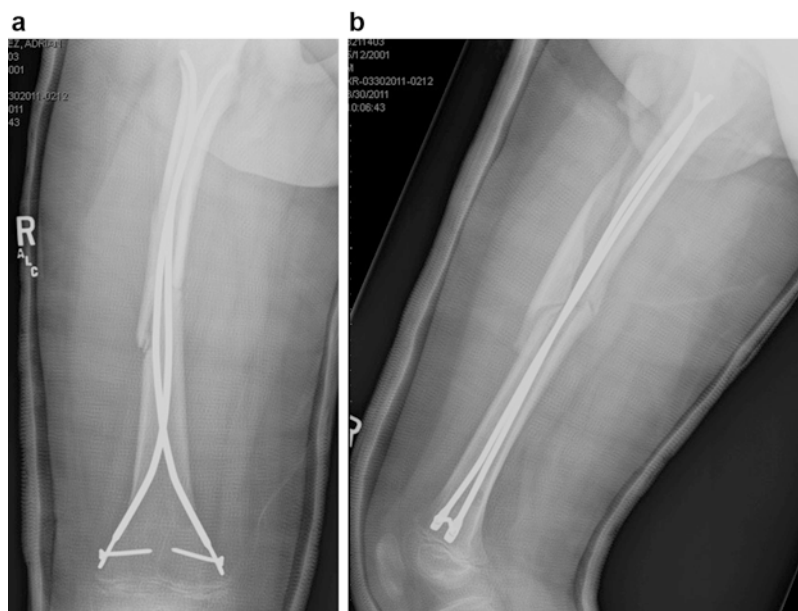


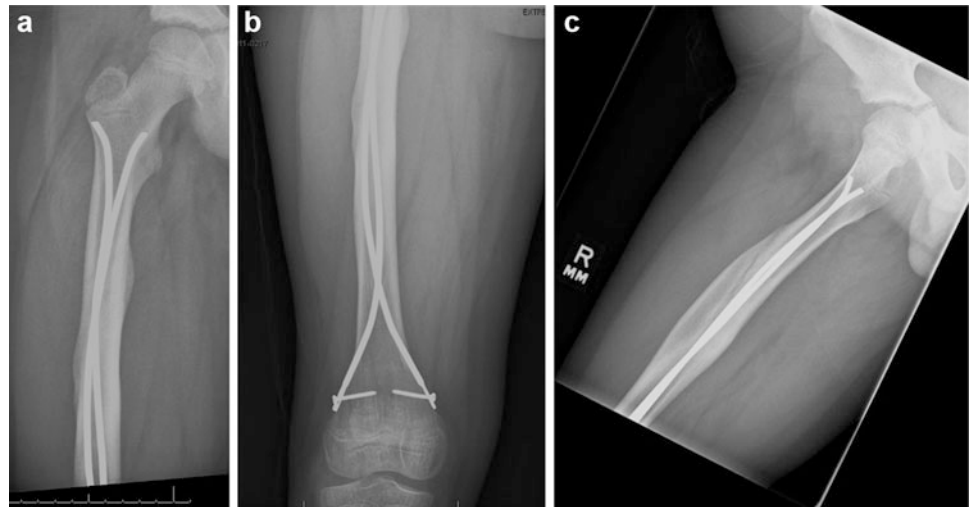
Fig. 4 AP (a) and lateral (b) radiographs 6 weeks from surgery demonstrate early callus formation. The patient was progressed to weight bearing as tolerated



Fig. 5 AP (a) and lateral (b) radiographs 10 weeks from surgery demonstrate maturing callus incorporating the butterfly fragment. The patient had full knee range of motion and symmetric rotational profiles of the hips, and no clinically apparent limb length difference was ambulating well with symmetric foot progression angles and no limp. She was therefore allowed gradual return to full activity



Fig. 6 AP (a and b) and Lateral (c) femur radiographs demonstrate complete healing of fracture 9 months from the time of surgery. The patient was participating in various athletic activities without difficulty. Limb lengths and lower extremity rotational profiles were symmetric



femur may result in over or under sizing depending on the position of the image intensifier. Nails are contoured to provide balanced opposing forces at the fracture site. Never use nails of unequal diameter as this results in unbalanced fixation and can result in coronal plane deformity. Once advanced to the fracture site, the distal ends of the nails are used as “handlebars” to apply traction and restore alignment. Nails are then advanced proximally. If nails are unable to be passed, consider downsizing. Assess the rotational profile of the contralateral hip preoperatively and compare the operative side once fixation has been achieved to verify that no significant malrotation is present.

8 Outcome Clinical Photos and Radiographs

See Fig. 6.

9 Avoiding and Managing Problems

Stainless steel flexible nails are more rigid than their titanium counterparts. Assure proper contouring at the proximal end to assist in directing the nails up the femoral canal. While the nails usually glance off the cortex opposite their site of insertion, excessive force applied while the nails are in contact with that cortex could result in cortical perforation. The addition of a spica cast allows safe use of locked intramedullary nails for length unstable fractures; failure to

do so could result in shortening should the patient weight bear. Occasionally, patients will feel the distal implants against the iliotibial band or vastus medialis. Avoiding prominence of the distal nail will minimize the incidence of this complication. Malunion is best avoided by careful assessment of reduction in all planes.

10 Cross-References

- ▶ Femoral Shaft Fracture: Flexible Intramedullary Nails
- ▶ Femoral Shaft Fracture: Plating
- ▶ Floating Knee: Combined Femoral and Tibial Fractures
- ▶ Open Femur Fracture with Soft Tissue Loss

References and Suggested Reading

- Cramer KE, Paul Tornetta III, Spero CR, Alter S, Miraliakbar H, Teefey J (2000) Ender rod fixation of femoral shaft fractures in children. *Clin Orthop Relat Res* 376:119–123
- Ellis HB, Ho CA, Podeszwa DA, Wilson PL (2011) A comparison of locked versus nonlocked enders rods for length unstable pediatric femoral shaft fractures. *J Pediatr Orthop* 31(8):825–833
- Kocher MS (2010) American Academy of Orthopaedic Surgeons clinical practice guideline on treatment of pediatric diaphyseal femur fracture. *J Bone Joint Surg Am* 92(8):1790. <https://doi.org/10.2106/JBJS.J.00137>
- Linhart WE, Roposch A (1999) Elastic stable intramedullary nailing for unstable femoral fractures in children: preliminary results of a new method. *J Trauma* 47(2):372–378

Pathologic Femoral Shaft Fracture

Courtney E. Sherman and David H. Michel

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Abstract

The treatment of pathologic diaphyseal femur fractures in the pediatric population is a difficult problem. There is a dichotomous treatment algorithm when considering these injuries, depending on whether the lesion appears to be benign or malignant. Some of these lesions may be identified at the time of fracture, while others may have been known prior to the injury, although this should not impact the final treatment. This chapter reviews two

cases which highlight the pertinent treatment strategies of each.

1 Benign

1.1 Brief Clinical History

A 14-year-old female was running in a cross-country meet and felt an acute snap in her right thigh. She had immediate pain and deformity. She was unable to bear weight and was placed in a Buck's traction variant per the EMS team. She was then transferred to the pediatric hospital where she was seen and evaluated by the emergency department staff. Radiographs were obtained and identified a pathologic right diaphyseal femur fracture. The patient was then placed

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in a J-splint per the orthopedic surgery team until the time of her surgery. In addition to plain radiographs, advanced imaging was obtained. Both the plain radiographs and advanced imaging (CT scan) were consistent with a benign lesion based on the well-defined borders, geographic lesion, no extension outside of the cortex, and no soft tissue mass. The imaging was reviewed with an orthopedic oncologist to confirm the lesion was most consistent with a benign bone lesion. The next day, operative treatment began with an open biopsy with curettage of the lesion which on frozen section confirmed benign pathology, followed by attempted standard intramedullary nailing. The surgical team sustained an iatrogenic subtrochanteric femur fracture, and, consequently, the surgical plan was changed to submuscular plating to address both fractures. Final pathology confirmed a benign bone cyst.

1.2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

1.3 Preoperative Problem List

1. Osseous lesion of the right femoral diaphysis
2. Pathologic fracture of the right femoral diaphysis
3. Definitive diagnosis of the lesion
4. Choice of fracture fixation

2 Treatment Strategy

The mainstays of treatment for benign lesions are preoperative immobilization and splinting, open biopsy at the time of fixation with curettage and possible bone grafting, followed by fracture fixation using age, weight, and fracture appropriate methods.

Appropriate field immobilization by the EMS team was completed. Appropriate radiographs were obtained in the emergency department, and the benign-appearing lesion was detected by the radiology and emergency department providers. Orthopedic surgery was contacted shortly after the patient's arrival to the hospital. The fracture was sufficiently immobilized with the use of a J-splint as the orthopedic oncologist was contacted for consultation.



Fig. 1 AP (a and b) and lateral (c) views demonstrate the pathologic diaphyseal femur fracture. Imaging is consistent with a benign lesion

Advanced imaging was also consistent with a benign lesion. It was determined that further treatment could be administered by the pediatric orthopedic surgeon and open biopsy with fracture reduction, using standard methods, following intraoperative confirmation of benign tissues by the pathologist.

Considering the patient was greater than 11 years old, was skeletally mature, and had suffered a length unstable fracture, it was determined that appropriate fracture reduction could be obtained using rigid intramedullary nailing. As with all pediatric patients, a trochanteric entry nail was selected to avoid the theoretical risk of piriformis entry of femoral head blood supply disruption. The most desirable starting point for trochanteric entry intramedullary nailing is the tip of the greater trochanter on the AP image and in the center of the trochanter on the lateral image. Lateralization of the starting point may lead to eccentric reaming and even iatrogenic fracture, as seen in this case. It was then determined that the best way to address both fractures was the use of a submuscular plate.

2.1 Basic Principles

1. Benign appearing lesions should undergo open biopsy and curettage with or without bone grafting at the time of fracture fixation, for confirmation of the absence of malignant histological characteristics.
2. For the skeletally mature patient with a length unstable femoral shaft fracture, treatment with either intramedullary nailing or submuscular plating is acceptable.
3. To avoid the risk of avascular necrosis of the femoral head due to compromise of the medial femoral circumflex artery (via the lateral epiphyseal artery), the trochanteric starting point is employed for femoral intramedullary nailing in the pediatric population.
4. Sound fracture reduction techniques must be employed during these cases, as in all other fracture cases in the absence of a benign lesion.
5. Union may take longer to occur at the site of a pathologic fracture, and these patients' postoperative weight-bearing restrictions should reflect this.

2.2 Images During Treatment

See Fig. 2.

2.3 Technical Pearls

1. Having a medical team who is well versed in orthopedic oncologic processes is paramount. Determining benign versus malignant during the preoperative period followed by accurate intraoperative sampling to rule out malignant features is paramount before continuing with normal fracture fixation.
2. For trochanteric entry femoral intramedullary nailing, the starting point is of paramount importance. One must use the tip of the greater trochanter on the AP view and the center of the trochanter on the lateral view to ensure appropriate nail trajectory and minimize the risk of malreduction or iatrogenic fracture.
3. While using submuscular plating, one may use the fracture reduction tools of their preference to assist in obtaining an acceptable reduction.
4. For diaphyseal fractures, relative stability which restores limb length, alignment, and rotation must be obtained. A bridge plating technique using a submuscular plate leads to secondary fracture healing.

2.4 Outcome Clinical Photos and Radiographs

See Fig. 3.

2.5 Avoiding and Managing Problems

1. Choosing the correct age and fracture-appropriate implant and utilizing the appropriate techniques remain mandatory. To avoid the theoretical risk of femoral head avascular necrosis using the piriformis starting point, intramedullary nailing in the pediatric population should be undertaken using a trochanteric starting point.
2. Additional implants must be available should intraoperative complications present themselves.
3. Postoperative weight-bearing restrictions should reflect the degree of injury, fracture reduction, and construct stability in order to mitigate the risk of refracture or nonunion.

3 Malignant

3.1 Brief Clinical History

A 5-year-old female had a 3-month history of right knee pain. Plain radiographs were obtained, and there was concern for a malignant process. Consultation to an orthopedic oncologist

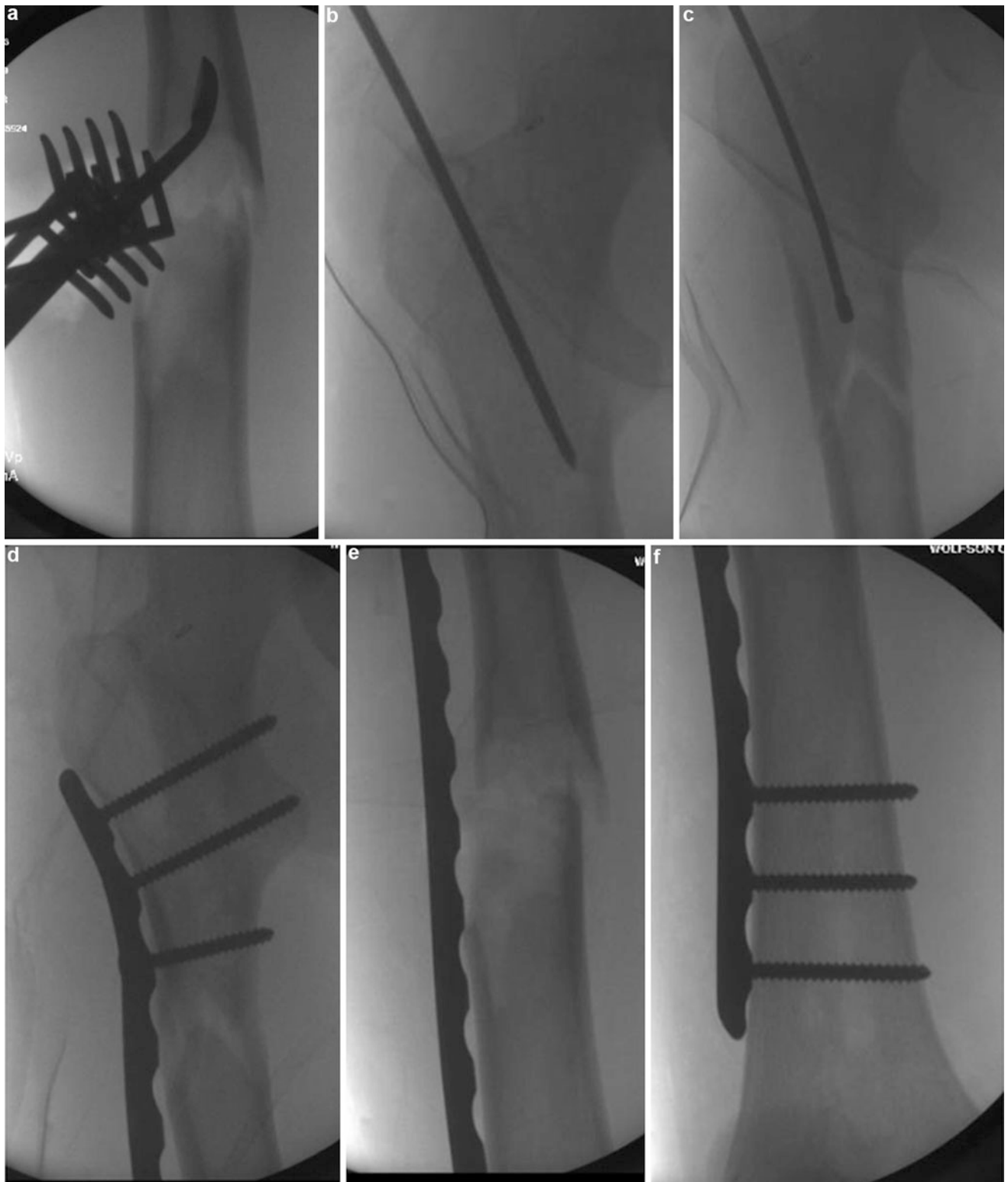


Fig. 2 Imaging showing intralesional curettage (a), the starting point with medial trajectory (b), resultant iatrogenic subtrochanteric fracture (c), and bridging reduction of both fractures using the submuscular plating technique (d–f)

was immediately made. During the period of time between the initial radiographs being obtained and her expedited appointment, she presented to the emergency department with acute

fracture through her lesion. She was then immobilized, and MRI was obtained which was consistent with a malignant process. The definitive diagnosis was completed via



Fig. 3 Radiographs at 4 months postoperative show acceptable alignment of the fractures with significant callus formation. Although there has been proximal screw failure, the construct has maintained its

alignment and allowed for fracture healing, and the patient was ambulating with no pain and no gait aides

CT-guided biopsy and confirmed osteosarcoma. It is important to obtain the biopsy under the direction of the treating orthopedic oncologist. She was then immobilized in a long leg cast during her chemotherapy course. Due to the involvement of the physis and the contamination of the compartment due to the pathologic fracture and her young age, rotationplasty was the best option for oncologic resection and functional preservation.

3.2 Preoperative Clinical Photos and Radiographs

See Fig. 4.

3.3 Preoperative Problem List

1. High-grade osteosarcoma
2. Right distal femur fracture, pathologic
3. Contamination of the compartment through the fracture site

3.4 Treatment Strategy

For pathologic fractures through malignant lesions, preoperative immobilization may be relied upon to provide stabilization for a prolonged period of time, pending the need for adjuvant chemotherapy. For this reason one may use splinting, casting, or application of an external fixator as methods of preoperative immobilization. The next step is definitive diagnosis of the lesion via either core needle biopsy or open biopsy. It is paramount that this be completed under the guidance of the treating orthopedic oncologist, as possible contamination of other compartments may negate the option for future limb salvage surgery or make the definitive surgery more involved for resection. Once a definitive diagnosis has been determined, then the appropriate oncologic medical treatment is delivered, such as adjuvant chemotherapy. Upon completion of the medical oncologic treatment, in coordination with the pediatric oncologist, the appropriate oncologic surgery will be planned and completed with the goal of negative margins.



Fig. 4 AP (a) and lateral (b) views demonstrate the prefracture imaging consistent with a malignant lesion. (c and d) MRI images demonstrate large marrow replacing lesion with periosteal elevation consistent with a

malignant lesion. The main differential would be osteosarcoma versus Ewing sarcoma

This may range from limb salvage vs. rotationplasty vs. amputation. It is important, when choosing the appropriate procedure, to keep in mind that once there has been a

pathologic fracture through the lesion, this is considered extracompartmental disease, and this contaminated region must be resected with the tumor.

For this patient, she was immobilized initially in a J-splint. MRI was then obtained which was again consistent with a malignant lesion. She was taken for CT-guided biopsy, although open biopsy is also an option. Biopsy confirmed a diagnosis of high-grade osteosarcoma. Staging was performed including whole-body bone scan and CT chest and was negative for metastasis. Once it was determined that she would need prolonged immobilization prior to operative intervention, she was placed in a long leg cast and changed intermittently. Medical oncology was then involved and administered the appropriate course of preoperative chemotherapy.

Due to the contamination of the compartment through the fracture, the location, and her age and future predicted growth, it was determined that she would be a candidate for Van Ness rotationplasty. Along with the pediatric orthopedic surgeon, her predicted growth was used with the goal of predicting her future knee length to plan that her ankle on her operative side will be at the same length of her predicted knee length on her contralateral side.

The patient then completed her postoperative chemotherapy. She did develop at femoral-tibial site nonunion and became symptomatic with localized pain at that location approximately 2 years postoperatively. Restaging at every 4 months has continued to be negative including whole-body bone scan, CT chest, and MRI of the primary site. CT confirmed the absence of recurrent tumor and showed the nonunion. It was then determined that she would benefit from revision of her plating to intramedullary nailing of her osteotomy site. Intraoperative pathology specimens and culture specimens were sent at the time of revision and were negative for infection and negative for neoplasm. Following her revision to an intramedullary nail, her osteotomy site united, and she is wearing her prosthesis with no pain.

3.5 Basic Principles

1. There must be temporary immobilization to allow for imaging with plain radiographs, MRI, and biopsy; splinting is sufficient at this time.
2. Diagnosis must be made with a tissue sample, which may be obtained via either CT-guided core needle biopsy or open biopsy.
3. Immobilization for the period of the preoperative chemotherapy course. Due to the prolonged nature of this period, casting or external fixation are recommended over splinting. External fixator should only be placed by treating orthopedic oncologist if chosen as immobilization method. Careful placement outside of the planned resection area is paramount.
4. Oncologic treatment per the medical oncology team usually consisting of multiagent chemotherapy for 8–12 weeks preoperatively.

5. Oncologist resection by orthopedic oncologist.
6. Postoperative chemotherapy for 6–12 months following the surgical intervention.
7. Continued monitoring with restaging every 4 months for the first 2 years consisting of plain radiographs, bone scan, and CT chest. After the first 2 years, restaging may be completed every 6 months until 5 years after resection.

3.6 Images During Treatment

See Figs. 5 and 6.

3.7 Technical Pearls

1. Referral and coordination of the patient's care with the treating orthopedic oncologist is essential once there is concern for a malignant primary bone tumor. From biopsy and immobilization to the operative procedure and follow-up, all of these should be supervised by the treating orthopedic oncologist.
2. All limb salvage procedures are technically demanding and require a great deal of experience. Planning is imperative, starting with the decision of where to obtain the biopsy. For our patient, the Van Ness rotationplasty was the best option considering her fracture, contamination, location, and age.
3. Careful preoperative imaging evaluation is important for planning resection with negative margins.

3.8 Outcome Clinical Photos and Radiographs

See Fig. 7.

3.9 Avoiding and Managing Problems

1. Treatment at a tertiary center by an orthopedic oncologist, pediatric medical oncologists, pathologists, and radiologists who are experienced in treating these difficult diagnoses helps to prevent delays in diagnosis, treatment, and management of complications.
2. Meaningful preoperative discussions with the patient and family cannot be overstated. It is essential that they have an understanding of the surgical options and the expected outcomes of each.
3. Having a diverse medical team at your disposal is also essential. Experienced prosthetists and therapists are a must to achieve the best patient outcomes.

Fig. 5 (a and b) demonstrates cast immobilization and callus formation during chemotherapy treatment

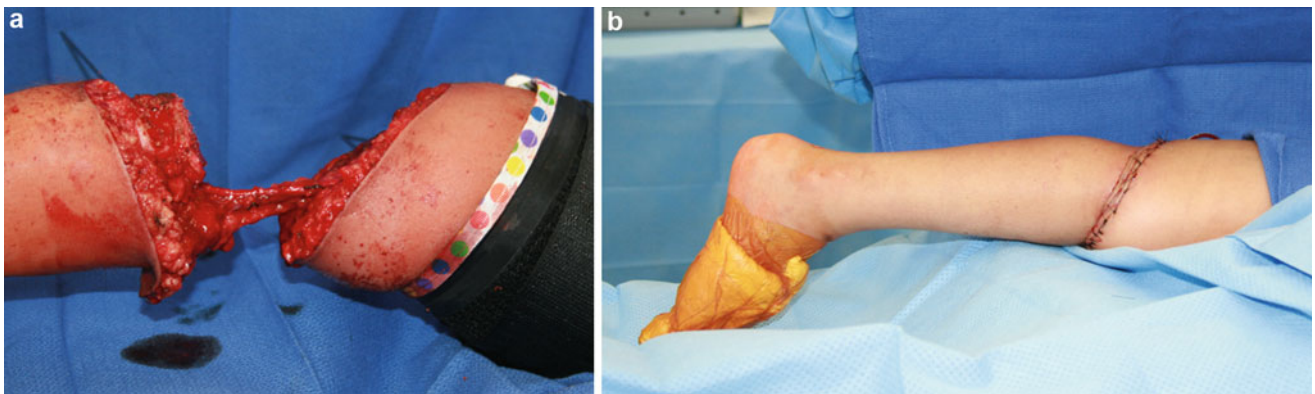


Fig. 6 (a and b) demonstrates intraoperative wide resection and preservation of the neurovascular bundle, and final closure after the rotationplasty is complete

4. Close oncologic and orthopedic follow-up are crucial. Nonunions following rotationplasty are not uncommon given the chemotherapy regimen and require a high index of suspicion to identify.
5. Physical exam, patient history, and serial imaging allow the surgeon to diagnose the nonunion prior to hardware failure.
6. Revision can be performed with a second ORIF/plating or intramedullary device. When the rotationplasty is performed, it is important to place the neurovascular bundle medially and plate laterally to allow for safe revision in the future.



Fig. 7 (a and b) Radiographs at 2 years show acceptable alignment but nonunion of the osteotomy site. (c) 3-month postoperative radiographs following revision to an intramedullary device with prosthesis in place. (d) 12-month postoperative radiographs demonstrating healed osteotomy

References and Suggested Reading

- Greenspan A, Jundt G, Remagan W (2007) Chapter 1: Differential diagnosis in orthopedic oncology. In: *Radiology and pathologic approach to bone tumors*, 2nd edn, Lipincott Williams & Williams, Philadelphia, pp 2–34
- Greenspan A, Jundt G, Remagan W (2007) Chapter 2: Differential diagnosis in orthopedic oncology. In: *Bone-forming (osteogenic) lesions*, 2nd edn, Lipincott Williams & Williams, Philadelphia, pp 40–128
- Ortiz EJ et al. *Pathologic fractures in children*. <https://www.ncbi.nlm.nih.gov/pubmed/15738811>
- Pretell-Mazzini J, Murphy RF, Kushare I, Dormanos JP (2014) Unicameral bone cysts: general characteristics and management controversies. *J Am Acad Orthop Surg* 22(5):295–303
- Roaten JD, et al. *Pediatric Femoral Shaft Fractures: a multicenter review of the AAOS clinical practice guidelines before and after 2009*. <https://www.ncbi.nlm.nih.gov/pubmed/28399048>
- Sim FH, Fuchs B (2004) Rotationplasty about the knee: surgical technique and anatomical considerations. *Clin Anat* 17(4):345–353

Open Femur Fracture with Soft Tissue Loss

Cheryl Lawing, Adam Margalit, and Michael Ain

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Abstract

High-grade **open femur fractures** in pediatric patients are high-energy injuries and 70% of patients have associated injuries. Despite the pediatric nature of the patient, these wounds are at high risk for **infection**, which can be as high as 50% in type III fractures. Thus, thorough debridement and timely administration of **prophylactic antibiotics** are essential. Fixation type largely depends on the age of the patient with consideration of the soft tissue injury. Internal fixation with intramedullary fixation, open reduction internal fixation (ORIF), or percutaneous fixation have been shown to have faster time to union than external fixation. These fractures are much slower to heal than closed pediatric femoral fractures, with full union taking potentially up to 32 weeks.

1 Brief Clinical History

A 7-year and 8-month-old boy was struck by a car while riding his bicycle. He had to be extricated from underneath the car. He sustained a right open femur fracture with an associated traumatic right knee arthrotomy.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

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Fig. 1 AP view of the right femur showing a severely displaced diaphyseal femur fracture with comminution



Fig. 2 Attempted lateral view injury film

3 Preoperative Problem List

- Right open femur fracture
- Right knee arthrotomy
- High risk for infection

4 Treatment Strategy

Treatment of the patient must begin with basic ATLS assessment, as these are high energy injuries and up to 70% of patients have been shown to have associated injuries (Hutchins et al. 2000). As in adults, immediate delivery of intravenous antibiotics is of utmost importance. **Cefazolin** is the mainstay of treatment, with **gentamicin** and **penicillin** being added for more grossly **contaminated** wounds. There is controversy regarding the duration of **antibiotic prophylaxis**, though most feel that 24 h is necessary with extension to 48 h for high-grade wounds (Hauser et al. 2006).

The patient should be taken as soon as reasonably possible to the operating room for thorough irrigation and debridement. Wounds should be extended to expose the entire zone of injury with debridement of all devitalized tissue. Low-pressure irrigation with normal saline has been shown to be effective and is considered by many to be less traumatizing to soft tissues than high-pressure irrigation (FLOW Investigators et al. 2015). In severely traumatized or contaminated wounds, a negative pressure dressing is an effective way to seal the wound and allow easy access for further debridement.

Following completion of thorough debridement, stable fixation must be achieved. Options include external fixation, flexible intramedullary fixation, reamed intramedullary fixation in children over 10 years of age, and bridge plating. The key reason for being unable to use a rigid intramedullary nail in children under 10 years old is concern for growth arrest following the inevitable violation of the greater trochanteric apophysis with resultant coxa valga, (Gonzalez-Herranz et al. 1995) though there is also concern for osteonecrosis of the femoral head. In the case of this patient, his wounds compromised entry points for flexible intramedullary nails and he was too young for a rigid IMN. Therefore, external fixation was utilized.

5 Basic Principles

The more severe the soft tissue loss and grade of fracture, the longer the time to union. The type of fixation used has also been shown to correlate with time to union, with external fixation taking longer for union than intramedullary fixation, ORIF, pins, and casting (Hutchins et al. 2000). However, soft tissue injury may preclude internal fixation, in which case external fixation remains a good option to quickly stabilize

the femur while allowing access for soft tissue care. In severe injuries where **vascular repair** is necessary, it may be necessary to shorten the femur to prevent excessive tension on the repair. Wounds without gross contamination and where the tissues are viable may be closed immediately. If there is concern and the need for further debridements, a wound vac **negative pressure dressing** is an excellent choice. Wounds can often be closed on a delayed manner, though plastic surgery intervention with split thickness skin grafting or flap coverage may be necessary.

6 Images During Treatment

See Figs. 3, 4, 5 and 6.

7 Technical Pearls

Thorough debridement of all devitalized tissue is essential and one should not hesitate to extend the wounds to fully expose the zone of injury and deliver the bone ends for debridement. Due to the open wound, direct manipulation of the bone ends is helpful for reduction, which allows one to remove any interposed soft tissue.



Fig. 3 AP view immediately post-operative. Due to soft tissue injuries overlying the distal third of the thigh, overlying the entry points for flexible intramedullary nails, the decision was made to treat the patient with external fixation



Fig. 4 Lateral view immediately post-operative. Due to soft tissue injuries overlying the distal third of the thigh, overlying the entry points for flexible intramedullary nails, the decision was made to treat the patient with external fixation



Fig. 5 AP view 4 weeks after treatment. Early callus formation is present though there is less than would be expected for a closed fracture

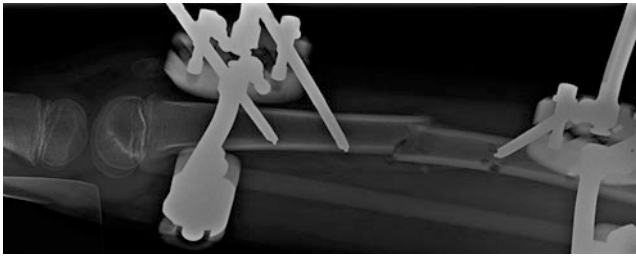


Fig. 6 Lateral view 4 weeks after treatment. Early callus formation is present though there is less than would be expected for a closed fracture



Fig. 7 AP view 6 months after the injury, after the external fixator has been removed. The fracture has achieved union with good alignment in the coronal plane



Fig. 8 Lateral view 6 months after the injury. While the fracture has healed, there is procurvatum at the fracture site. This deformity was not symptomatic

(Hutchins et al. 2000). The infection rate in this study found a 50% infection rate for type III fractures, while the malunion rate for this severity of fracture was 20%. Thus, the importance of thorough debridement and appropriate antibiotic management cannot be overemphasized. Grossly contaminated wounds should be brought back to the OR for repeat irrigation and debridements. It is important to note that osteomyelitis can manifest late in a patient's course of treatment, though it usually occurs in an acute manner.

8 Outcome Clinical Photos and Radiographs

See Figs. 7 and 8.

9 Avoiding and Managing Problems

In the largest review of pediatric open femur fractures, time to union was significantly correlated with the degree of injury. Healing averaged 11.1 weeks for type I fractures, 17.0 weeks in type II fractures, and 31.8 weeks in type III fractures

10 Cross-References

- [Femoral Shaft Fracture: Flexible Intramedullary Nails](#)
- [Tibial Shaft Fracture with Soft Tissue Loss](#)

References and Suggested Reading

FLOW Investigators, Bhandari M, Jeray KJ, Petrisor BA, Devereaux PJ, Heels-Ansdell D, Schemitsch EH, Anglen J, Della Rocca GJ, Jones C, Kreder H, Liew S, McKay P, Papp S, Sancheti P, Sprague S, Stone TB, Sun X, Tanner SL, Tornetta P 3rd, Tufescu T, Walter S, Guyatt GHA (2015) Trial of wound irrigation in the initial management of open fracture wounds. *N Engl J Med* 373(27):2629–2641

- Gonzalez-Herranz P, Burgos-Flores J, JM Rapariz JA, Lopez-Mondejar JG, Ocete S (1995) Amaya. Intramedullary nailing of the femur in children. Effects on its proximal end. *J Bone Joint Surg Br* 77(2):262–266
- Hauser CJ, Adams CA, Eachempati SR (2006) Council of the Surgical Infection Society Surgical Infection Society guideline: prophylactic antibiotic use in open fractures: an evidence based guideline. *Surg Infect* 7:379–405
- Hutchins CM, Sponseller PD, Sturm P, Mosquero R (2000) Open femur fractures in children: treatment, complications, and results. *J Pediatr Orthop* 20(2):183–188

Supracondylar Femur Fracture: Treatment with a Submuscular Plate

Kevin M. Neal

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Abstract

Distal femoral fractures in older children and adolescents require stabilization to avoid potential malunions. This chapter discussed the indications for operative management of distal femoral fractures and the technique of using a lateral, submuscular plate for internal fixation.

A 15-year-old boy fell from a fence and injured his left leg. He had immediate pain, swelling in the thigh, and the inability to move the leg. Radiographs in the emergency department revealed a distal femur fracture through the metaphysis and above the physis. He was splinted and scheduled for open reduction with internal fixation. After a discussion of options with the family, the patient was given a general anesthetic, and an open reduction with internal fixation was performed using a laterally based locking submuscular plate. Postoperatively, the patient

was allowed to bear weight as tolerated using crutches for protection and to perform range of motion exercises for the knee and hip. The plate was removed approximately 6 months following the original surgery.

1 Brief Clinical History

A 15-year-old boy injured his left leg after a fall off of a fence while caring for livestock at his family's farm. He had immediate pain, swelling, deformity, and the inability to move the left knee or walk. Evaluation in the emergency department revealed a distal femur fracture (Fig. 1), with intact motor and sensory function in the left foot, as well as a normal dorsalis pedis pulse and normal capillary refill. A long leg posterior splint was applied, and the patient was scheduled for operative fixation of the distal femur fracture.

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Fig. 1 AP (a) and lateral (b) views of the left knee, demonstrating a metaphyseal distal femoral fracture



2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Left distal femoral metaphyseal fracture

4 Treatment Strategy

Conservative management of distal femur fractures in older children and adolescents risks the possibility of malunion. There are several different methods available to achieve adequate fixation, including external fixation, intramedullary nailing, and plating. External fixation is an acceptable option but carries risks of pin-tract infection and perhaps patient dissatisfaction related to the psychological aspects of the external device and subsequent unpleasing scars. External fixation in the distal femoral metaphysis may require the use of transverse wires, rather than half pins, which may cause more tissue irritation. Fixation with flexible or rigid intramedullary nailing is also a viable option. Because there is less room for purchase of intramedullary devices in proximal and distal femoral shaft fractures, and the devices are typically not wide enough to engage cortical bone at these levels, this option may be more technically difficult, and these fractures have potential to displace despite the IM devices. Plating provides rigid internal fixation, and locked plating may provide improved stability in the weaker

cancellous bone of the metaphysis. Plating allows a quick return to weight bearing and unrestricted knee and hip range of motion without the need for supplemental immobilization. Most patients will choose to have the implants removed after a period of adequate healing.

5 Basic Principles

1. The procedure can be performed with the patient positioned supine on a regular radiolucent table or a fracture table.
2. If a fracture table is used, traction and appropriate abduction, adduction, flexion, and extension are applied through the hip to achieve a reduction. The reduction is then maintained by the fracture table while the plate is applied. If the reduction cannot be achieved by closed methods, direct manipulation of the fracture fragments is possible after exposure.
3. A longitudinal incision is made laterally over the distal femoral metaphysis.
4. The iliotibial band is split longitudinally, and the vastus lateralis is elevated superiorly to expose the lateral extra-periosteal-submuscular space.
5. An appropriately sized plate is chosen. Typical available sizes include 3.5 mm plates for smaller patients and 4.5 mm plates for larger patients.
6. Some precontoured plates are commercially available. Otherwise, the plate should be bent using a tabletop plate bender, to mimic the contour of the lateral distal femur. Fluoroscopy should be used to check the contours of the plate.

7. The fracture is reduced, and the plate is applied to the lateral aspect of the distal femur. Because the fracture is in a distal location, adjacent to the skin incision and exposure, direct manipulation of the fragments and removal of any interposed tissue from the fracture site are possible at this point.
8. A second longitudinal incision is made over the proximal aspect of the plate to expose three or four proximal holes.
9. K-wires are applied through locking towers attached to the plate proximally and distally. The position of the plate and fracture reduction is then confirmed on AP and lateral fluoroscopy.
10. Reduction of residual translation can be accomplished by using nonlocking screws, applied through the plate to lag the bone closer to the plate.
11. Locking screws can be used if the contour of the plate does not exactly match the contour of the distal femur or for improved stability in the softer cancellous bone of the metaphysis.
12. Three or four screws are applied proximal and distal to the fracture site to stabilize the fracture (Fig. 2). Non-locking screws used for reduction should be applied before locking screws, but screws used for fixation rather than reduction can be applied in any order. The author prefers to use locking screws preferentially, to provide added stability in the softer metaphyseal bone, and to account for imperfect contouring of the plate to the curved lateral distal femur. Theoretically, using locking screws also avoids compression of the plate to the lateral aspect of the bone, preserving the periosteal vessels.
13. Unused holes in the central third of the plate can remain unfilled.
14. The iliotibial band and skin are closed using absorbable suture.
15. Partial weight bearing can be initiated postoperatively, progressing relatively rapidly to weight bearing as tolerated as bony healing is confirmed.
16. No postoperative immobilization is required.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

1. When using a fracture table, fluoroscopy can be used to confirm an adequate reduction after positioning and prior to the surgical incision.
2. The plate can be held against the distal lateral aspect of the femur using provisional K-wires. The position of the plate and reduction can be checked using fluoroscopy prior to placing the screws.
3. Some commercially available plates have distal locking screw holes with the screw trajectory designed to run *parallel to the physis* (Fig. 2). When using a locking plate with screw trajectories *perpendicular to the plate*,

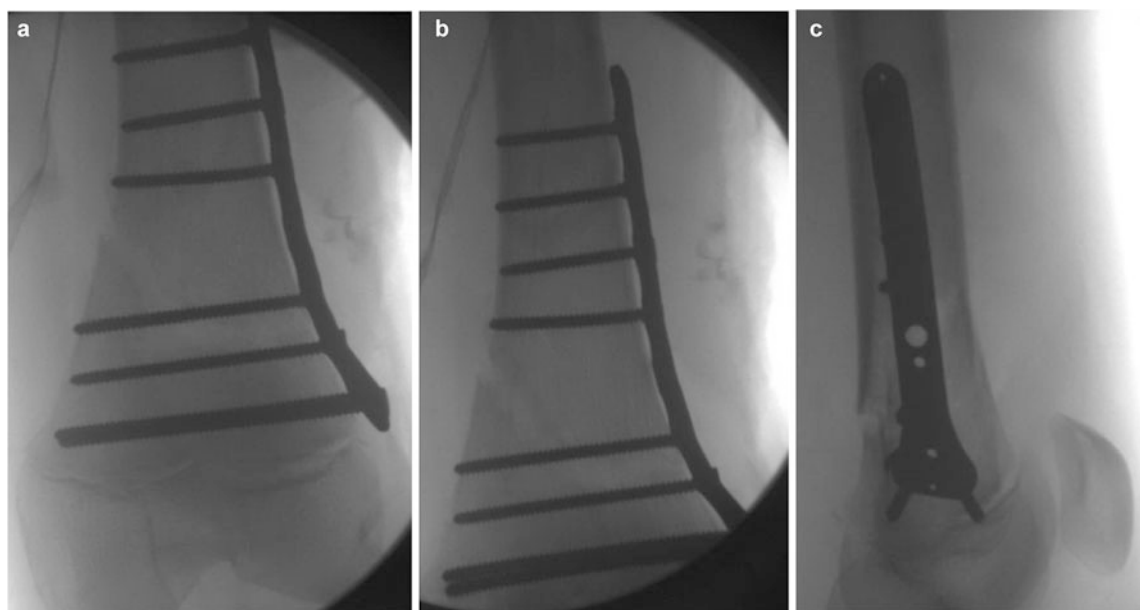


Fig. 2 AP (a, b), and lateral (c) views of the left distal femur, showing the supracondylar distal femur fracture fixed using a submuscular locking plate. A near-anatomic reduction has been achieved

Fig. 3 AP (a) and lateral (b) views of the left knee, 10 months after the injury and 2 months following implant removal, showing adequate healing and alignment. The patient is now skeletally mature



care must be taken to avoid the physis. This can be accomplished by using nonlocking screws placed parallel to the physis or shorter locking screws that do not cross the physis.

4. The fracture site is typically close to the plate insertion site. Gentle dissection can be done at the fracture site, if needed to remove any interposed muscle or periosteal tissue.
5. Nonlocking screws can be applied first through the plate to lag the bone to the plate and reduce any residual translation.

2. Changing the distal femoral alignment during screw placement can be avoided by using locking screws. Because locking plates and screws do not rely on compressing the plate to the bone surface, alignment can be maintained even if the contours of the distal femur and the contours of the plate are slightly different.

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

1. Precontoured locking plates have a flare meant to match the normal contours of the lateral distal femur. They are based on normal averages from anatomic specimens. To ensure normal distal femoral alignment and avoid varus or valgus positioning, make sure that the reduction is as close to anatomic as possible using fluoroscopy.

10 Cross-References

- [Femoral Shaft Fracture: Flexible Intramedullary Nails](#)

References and Suggested Readings

- Hedequist D, Bishop J, Hresko T (2008) Locking plate fixation for pediatric femur fractures. *J Pediatr Orthop* 28(1):6–9
- Li Y, Hedequist DJ (2012) Submuscular plating of pediatric femur fracture. *J Am Acad Orthop Surg* 20(9):596–603
- Porter SE, Booker GR, Parsell DE, Weber MD, Russell GV, Woodall J Jr, Wagner M, Neubauer T (2012) Biomechanical analysis comparing titanium elastic nails with locked plating in two simulated pediatric femur fracture models. *J Pediatr Orthop* 32(6):587–593
- Samora WP, Guerriero M, Willis L, Klingele KE (2013) Submuscular bridge plating for length-unstable, pediatric femur fractures. *J Pediatr Orthop* 33(8):797–802
- Wilson CH, Smith CS, Gay DM, Loveless EA (2012) Submuscular locked plating of pediatric femur fractures. *J Surg Orthop Adv* 21(3):136–140

Treatment of a Pediatric Open Supracondylar Femur Fracture with External Fixation

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Abstract

This chapter describes the treatment of a comminuted supracondylar femur fracture secondary to a gunshot wound using a multiplanar external fixator. The principles and technique of external fixation in this situation are discussed.

wound medially and exit wound laterally in the distal right thigh with oozing from these. She had palpable pedal pulses and brisk capillary refill, less than 2 s, in the toes.

1 Brief Clinical History

A 6-year-old, otherwise healthy, girl was brought into the emergency room after being accidentally shot as an innocent bystander. She was pale and hypovolemic and was noted to have an isolated injury to the right thigh. She had entry

2 Preoperative Clinical Photos and Radiographs

Radiographs (Fig. 1a, b) demonstrated a comminuted supracondylar femur fracture on the right side. There did not appear to be physeal or articular involvement. There were no other fractures noted.

3 Preoperative Problem List

1. Open wounds, soft tissue injury
2. Fracture comminution
3. Close proximity to the growth plate
4. Limited real estate for fixation

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Fig. 1 (a) and (b): Injury radiographs of the right femur anteroposterior (a) and lateral views (b) show a comminuted distal femoral metadiaphyseal fracture



4 Treatment Strategy

After initial resuscitation in the emergency room, she was brought up to the operating room for debridement of the wounds and stabilization of the femur. Her wounds were debrided carefully, and the wounds were thoroughly irrigated out. The fracture was comminuted, and there was little room between the physis and the fracture. It was therefore decided to stabilize it with a circular external fixator. We started with a transverse wire parallel to the physis and just proximal to it. The distal ring was mounted on this wire. We then added two hydroxyapatite 4 mm Schanz screws (tapered core) into the distal fragment after holding the ring parallel to the joint in both planes. The Schanz screws were placed along the medial intermuscular septum (posteromedial to anterolateral) and along the lateral intermuscular septum (posterolateral to anteromedial) to minimize any quadriceps impingement.

We then placed a two-thirds ring perpendicular to the proximal fragment. This was open medially to allow room for the contralateral thigh. This was attached to the proximal fragment with three hydroxyapatite coated 4 mm Schanz screws. These were placed from posterolateral to anteromedial and anterolateral to posterolateral. The distalmost screw was placed approximately 2–3 cm away from the fracture site (out of the zone of microfracture). This minimized the free bending stretch (distance of the bone around the fracture that is unsupported by the frame). The remaining two Schanz screws were spread out using Rancho cubes, to offset them from the proximal ring and maximize the pin

pitch (i.e., distance between the pins). The rings were then connected with struts, which would enable fine-tuning of the fracture alignment. After aligning the fracture, the struts were locked. This resulted in stable fixation of the fracture. This was confirmed by taking the knee and hip through a range of motion check. The wounds were left open and dressings were applied.

5 Basic Principles

1. Span the zone of injury.
2. Stable fixation for extensive comminution necessitates multiplanar fixation.
3. Maximize pin pitch (distance between pins in each fragment).
4. Minimize free bending stretch (near-near, far-far pin placement).
5. Leave adequate room for soft tissue management.

6 Images During Treatment

Check radiographs were obtained, which demonstrated appropriate alignment in both planes (Fig. 2a, b).

The wounds were treated with dressing changes and allowed to heal secondarily. Pin care was instituted, and range of motion exercises at the knee and hip were initiated immediately postop. She proceeded to start weight bearing as tolerated and had progressive callus formation and went on to heal the fracture (Fig. 3a, b), and the frame was removed in 10 weeks.

7 Technical Pearls

1. With an external fixator for a femur fracture, one would prefer at least two pins on either side of the fracture (preferably three pins to have a more rigid construct).
2. Factors increasing the stability of the frame:
 - (a) Having fixation in more than one plane.
 - (b) Having the frame close to the skin and bone (but leaving adequate room for skin care and wound care, usually approximately two finger breaths).
3. Use of hydroxyapatite-coated pins minimizes loosening.
- (c) Minimizing the free bending stretch and maximizing the pin pitch (near-near, far-far pin placement).
- (d) Using the largest appropriate diameter pins. Hydroxyapatite coated tapered core pins to decrease loosening.
- (e) Use of full rings vs. partial (two-third) rings.

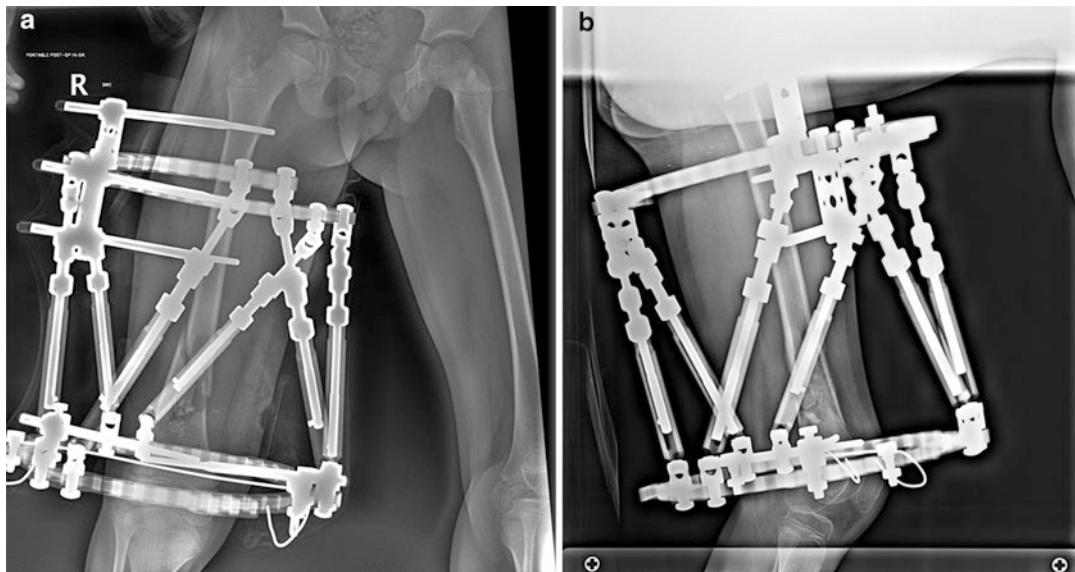
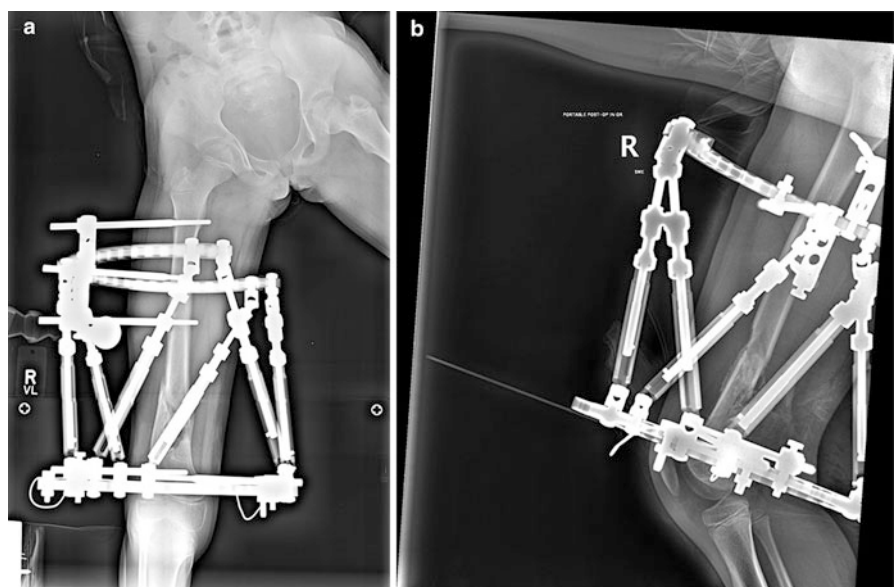


Fig. 2 (a) and (b): Postoperative radiographs demonstrating appropriate reduction with Taylor Spatial frame in place

Fig. 3 (a) and (b): Radiographs showing healing of the fracture with bridging callus



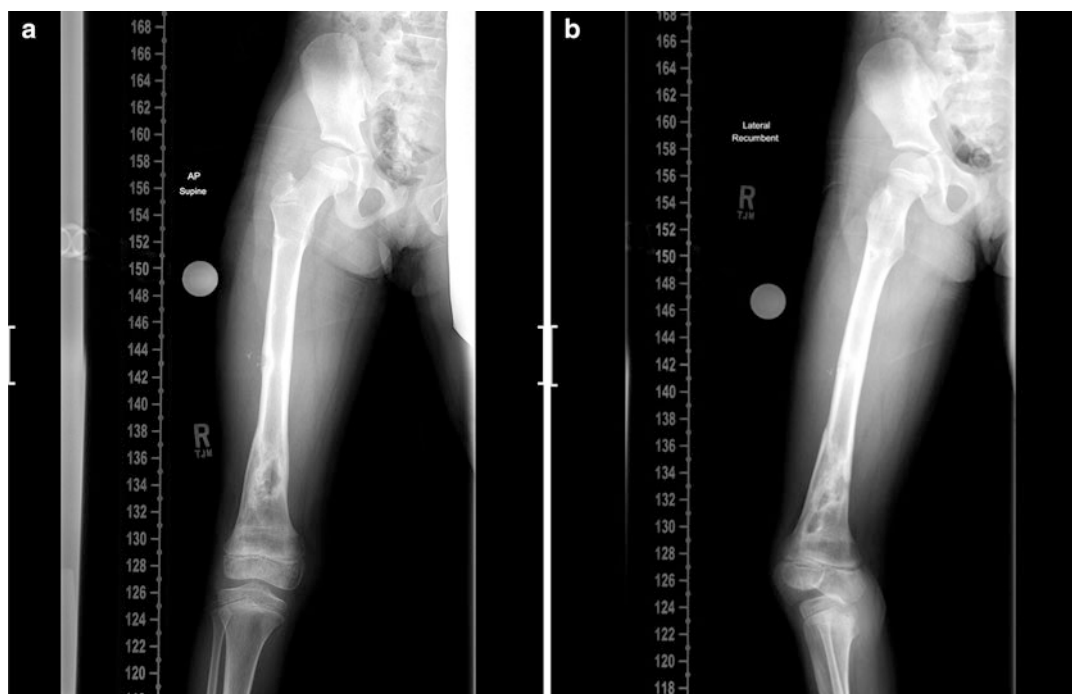


Fig. 4 (a) and (b): Radiographs after removal of the fixator demonstrate healing of the fracture in anatomic alignment

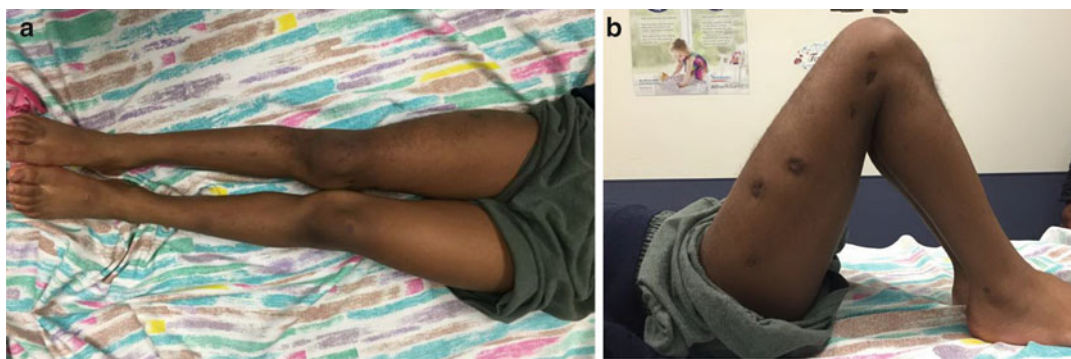


Fig. 5 (a) and (b): Clinical photographs after frame removal demonstrate appropriate alignment and good range of motion at the knee

4. Placement of pins along the intermuscular septa both medially and laterally helps minimize impalement of the quadriceps by the pins, minimizing knee stiffness.
5. Ranging the knee intraoperatively helps identify any impingement and muscle impalement and correct it appropriately.

8 Outcome Clinical Photos and Radiographs

She continued to work on ROM and advanced to full activity in 12 weeks after removal of the frame. (Figs. 4a, b and 5a, b). She was noted to have mild overgrowth (less than 1 cm) of the femur at 9-month follow-up (Fig. 6).

9 Avoiding and Managing Problems

9.1 Decision-Making

In length-unstable fractures in young children with femur fractures, the options typically include submuscular plating vs. external fixation. In this case, with extensive comminution and open gunshot wounds, the preferred option was an external fixator.

Behrens outlined the principles of external fixation in trauma situations. These include avoiding damage to vital structures, allowing access to the injured area, and meeting the mechanical demands of the patient and the injury. In this case, we preferred



Fig. 6 Anteroposterior radiograph of bilateral lower extremities demonstrates minimal overgrowth of the femur at 9 months postoperatively

a circular external fixator over a monolateral frame. The circular fixator gave us the ability to place two half pins and a wire in the short distal fragment, which we could not with a monolateral external fixator. This improved the stability of the construct.

10 Cross-References

- [Femoral Shaft Fracture: Flexible Intramedullary Nails](#)
- [Femoral Shaft Fracture: Plating](#)
- [Pathologic Femoral Shaft Fracture](#)

References and Suggested Reading

- Behrens F (1989) General theories and principles of external fixation. *Clin Orthop* 241:15–23
- Calhoun JH, Li F, Ledbetter BR, Gill CA (1992) Biomechanics of the Ilizarov external fixator for fracture fixation. *Clin Orthop Relat Res* 7(280):15–22
- Gasser B, Boman B, Wyder D et al (1990) Stiffness characteristics of the circular Ilizarov device as opposed to conventional external fixators. *J Biomech Eng* 112:15–21
- Moroni A, Faldini C, Pegreffi F et al (2002) Fixation strength of tapered versus bicylindrical hydroxyapatite-coated external fixation pins: an animal study. *J Biomed Mater Res* 63:61–64
- Pommer A, Muhr G, David A (2002) Hydroxyapatite-coated Schantz pins in external fixators for distraction osteogenesis: a randomized, controlled trial. *J Bone Jt Surg Am* 84:1162–1166
- Solomin L (ed) (2012) *The basic principles of external skeletal fixation using the Ilizarov and other devices*. Springer, Milan

Salter-Harris I Fracture of the Distal Femur

Kevin M. Neal

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Abstract

Salter-Harris I and II fractures of the distal femur in children are relatively uncommon injuries but have significant implications for limb alignment and future growth. Restoration of normal limb alignment requires fracture reduction and fixation in a near-anatomic position, without risking further damage to the growing physis. Because of the undulating nature of the distal femoral physis, and the propensity for Salter-Harris I and II fractures in this location to cross different zones of the growing physis, these fractures are among the most likely to lead to permanent physeal arrest. This chapter discusses the nature of these injuries, the author's preferred fixation technique, and the necessity to monitor patients long term for potential growth arrest.

A 10-year-old boy presented after falling on a trampoline with pain and deformity in the left knee. X-rays in the emergency department revealed a displaced fracture through the left distal femoral physis. Under a general anesthetic, the fracture was reduced and pinned percutaneously. A supplemental long leg cast was used to immobilize the knee. The pins were removed under a second general anesthetic about 4 weeks later, and physical therapy for knee range of motion and quadriceps strengthening was initiated. The patient regained normal function of the knee and was subsequently followed to evaluate for a physeal arrest.

1 Brief Clinical History

A 10-year-old boy injured his left knee while jumping on a trampoline. He had immediate pain, swelling, deformity, and the inability to walk on the left side. Evaluation in the

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Fig. 1 AP (a) and lateral (b) views of the left knee demonstrating a displaced Salter-Harris I fracture through the distal femoral physis



emergency department revealed a left knee deformity, with intact motor and sensory function in the left leg, as well as a normal dorsalis pedis pulse and normal capillary refill (see Fig. 1).

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Salter-Harris I fracture of the left distal femur.

4 Treatment Strategy

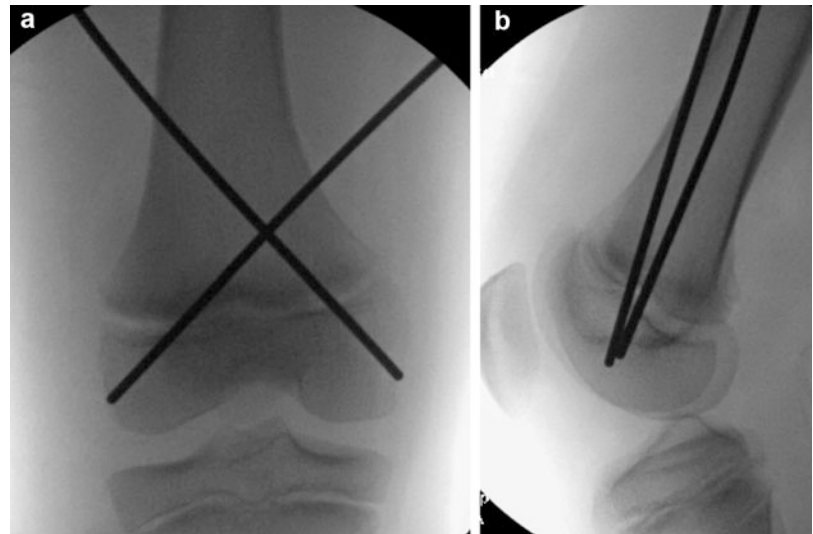
Treatment options include closed manipulation and casting, percutaneous fixation, external fixation, or open reduction with internal fixation. Treatment without reduction is not indicated for displaced fractures. Though closed manipulation and casting is an option, Salter-Harris I fractures of the distal femur have significant potential for instability, which could lead to malunion. External fixation is an option but would require placing multiple percutaneous pins in the relatively small distal femoral epiphysis and might also require spanning the knee for stability. Internal fixation is possible but would require implants crossing the distal femoral physis, which could increase the risk for growth arrest. Percutaneous fixation with smooth wires provides adequate

stability for healing, without significantly increasing the risk for physeal arrest.

5 Basic Principles

1. Manipulation of the fracture is performed, and adequate reduction is confirmed on multiplanar intraoperative fluoroscopy.
2. Long K-wires are started medially and laterally in the epiphysis of the distal femur and driven proximally across the fracture, through the far cortex of the distal femur, and out through the skin.
3. The K-wires are retrieved proximally and pulled until the distal ends are entirely within the distal femoral epiphysis.
4. The K-wires are cut beneath the skin, allowing normal soft tissue healing (see Fig. 2).
5. A well-padded cylinder or long leg cast is applied with the knee in extension.
6. Weight bearing with crutches is allowed.
7. The pins are removed through a percutaneous stab incision under a second anesthetic, approximately 4 weeks following the injury.
8. Physical therapy can be initiated for knee range of motion and quadriceps strengthening.
9. Expect adequate motion and strength in the knee to allow a return to activity without restrictions 6–12 weeks following pin removal.
10. The patient should be followed to skeletal maturity to evaluate limb length and alignment. Partial or complete physeal arrest from the injury to the distal femoral physis is common.

Fig. 2 AP (a) and lateral (b) views of the left knee demonstrating a near-anatomic reduction of the Salter-Harris I fracture of the distal femur, with intact percutaneous K-wires pulled flush into the distal femoral epiphysis



11. Standing full-length hip to ankle X-rays are obtained at 6 months, 1 year, and 2 years following the injury.
12. If physeal arrest is noted during follow-up, options for treatment include observation, guided growth, permanent arrest with contralateral arrest, or physeal bar resection.
5. A well-padded, well-molded long leg cast with the knee in extension protects the fracture site and allows weight bearing with crutches and ankle range of motion.
6. Following pin removal, a knee immobilizer can be used for comfort while physical therapy is advanced.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

1. Placing a towel bump beneath the distal femoral metaphysis can aid reduction and maintain stability to allow percutaneous pin placement.
2. Starting the pins slightly posteriorly in the distal femoral epiphysis, and directing them anteriorly, helps ensure that they exit the skin and soft tissues anterior to Hunter's canal in the thigh. Alternatively, the pins can both be placed entering from the lateral side, one antegrade and one retrograde to avoid the medial side all together.
3. Cutting the pins beneath the skin avoids problems with pin site infection in the large soft tissue envelope of the thigh. Leaving pins percutaneously distally could result in seeding of the knee joint and septic arthritis. In addition to the risks of infection, removal of large K-wires is typically uncomfortable in children in a clinic setting.
4. Sutures are not required for the small wounds required to place and remove the pins. Steri-Strips applied to the wounds are adequate for healing.

8 Outcome Clinical Photos and Radiographs

There are no figures available.

9 Avoiding and Managing Problems

1. Reduction of the fracture can typically be accomplished with gentle manipulation of the knee, preventing further damage to the distal femoral physis.
2. Discussion with the family regarding the potential for growth arrest and the need for future evaluation should be done at the time of surgery and repeated at each subsequent visit.
3. Leaving K-wires buried beneath the skin minimizes the risk for pin site infection.

10 Cross-References

- ▶ [Salter-Harris II Distal Femur Fracture](#)
- ▶ [Salter-Harris III Distal Femur Fracture](#)
- ▶ [Salter-Harris IV Distal Femur Fracture](#)

References and Suggested Readings

- Arkader A, Warner WC Jr, Horn BD, Shaw RN, Wells L (2007) Predicting the outcome of physeal fractures of the distal femur. *J Pediatr Orthop* 27(6):703–708
- Cassebaum WH, Patterson AH (1965) Fractures of the distal femoral epiphysis. *Clin Orthop* 41:79–91
- Czitrom AA, Salter RB, Willis RB (1981) Fractures involving the distal epiphyseal plate of the femur. *Int Orthop* 4(4):269–277
- Dahl WJ, Silva S, Vanderhave KL (2014) Distal femoral physeal fixation: are smooth pins really safe? *J Pediatr Orthop* 34(2):134–138
- Garrett BR, Hoffman EB, Carrara H (2011) The effect of percutaneous pin fixation in the treatment of distal femoral physeal fractures. *J Bone Joint Surg Br* 93(5):689–694
- Graham JM, Gross RH (1990) Distal femoral physeal problem fractures. *Clin Orthop* 255:51–53
- Riseborough EJ, Barrett IR, Shapiro F (1983) Growth disturbances following distal femoral physeal fracture-separations. *J Bone Joint Surg Am* 65(7):885–893
- Roberts JM (1973) Fracture separation of the distal femoral epiphyseal growth line. *J Bone Joint Surg Am* 55:1324
- Thomson JD, Stricker SJ, Williams MM (1995) Fractures of the distal femoral epiphyseal plate. *J Pediatr Orthop* 15(4):474–478

Salter-Harris II Distal Femur Fracture

Jeanne M. Franzone and Richard W. Kruse

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Abstract

A 13-year-old boy sustained a closed displaced Salter-Harris II fracture of the right distal femur when struck by a truck as a pedestrian while walking home from school. This injury was part of a high energy injury with a concussion, pulmonary contusions, and multiple additional contusions and abrasions. Following initial trauma evaluation and stabilization, he was treated with open reduction and internal fixation. He was initially allowed to perform toe touch weightbearing on the right leg while wearing a knee immobilizer. At two and a half weeks postoperatively he was transitioned to a hinged knee brace with 0–40° of motion and instructed to begin working on straight leg raises to address his quadriceps atrophy and weakness. At 6 weeks postoperatively he was given full range of motion in a hinged knee brace and he required

further work with physical therapy on range of motion and strengthening. He was seen 1 year postoperatively to evaluate his leg lengths and alignment.

1 Brief Clinical History

A 13-year-old healthy boy was brought in by ambulance after being struck by a truck while walking home from school. He had a loss of consciousness at the site of injury. A full trauma evaluation and workup was completed in the emergency room and demonstrated a concussion, pulmonary contusions, multiple contusions and abrasions, and a closed Salter-Harris II fracture of the right distal femur. He was able to follow motor commands and his neurovascular status was intact. His right lower extremity was stabilized in a splint. He was closely monitored and when cleared by the trauma team was taken to the operating room the following day for open reduction and internal fixation of the right distal femur.

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Fig. 1 Anteroposterior (a) and lateral (b) views of the right distal femur demonstrating a displaced Salter-Harris II fracture



2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Displaced Salter-Harris II fracture of the right distal femur
2. Additional injuries (high energy trauma)

4 Treatment Strategy

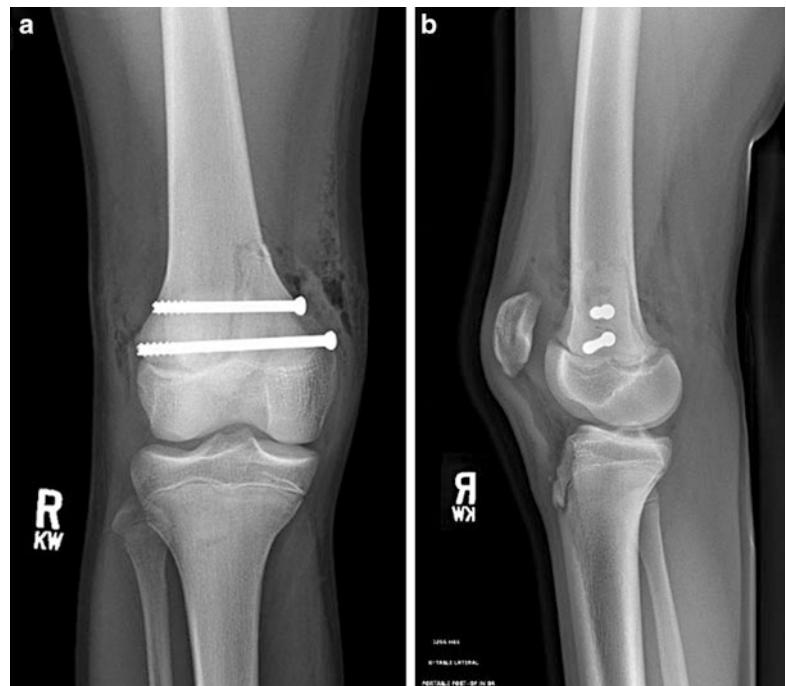
The initial treatment strategy for a displaced Salter-Harris II fracture of the distal femur depends on the degree of displacement of the fracture as well as the neurovascular status of the patient. A significantly displaced fracture with abnormal distal pulses or perfusion requires urgent reduction. If perfusion is compromised following closed reduction, urgent exploration and possible vascular repair with stabilization of the fracture fragment is indicated. In this case, the fracture was closed and the neurovascular status was intact. Initial stabilization was provided with a long leg J-splint and close observation was performed while the patient's other injuries were assessed. The feasibility of closed reduction is determined intraoperatively with a low threshold for open reduction to minimize physeal trauma and the risk of subsequent growth arrest. In the setting of an open reduction, the surgical approach is determined by the fracture pattern and the direction of displacement. Obstacles to closed reduction tend to be

at the apex of the deformity. Anything less than anatomic reduction increases the risk of growth disturbance. Given a high rate of redisplacement with immobilization in a long leg cast following closed reduction of displaced distal femoral physeal fractures, stable internal fixation is indicated. In this case, the large size of the metaphyseal Thurstan-Holland fragment made it amenable to screw fixation avoiding the physis. If it is necessary to cross the physis to achieve stable fracture fixation, consideration should be given to smooth wires. Families must be cautioned regarding the risk of growth disturbance in the form of angular deformity, leg length discrepancy or both forms of deformity and the need for follow-up for at least a year beyond fracture healing.

5 Basic Principles

1. In addition to a full trauma evaluation, it is important to evaluate the neurovascular status of the injured limb with attention to pulses, color, temperature, and sensory and motor assessments. The popliteal artery and its branches are vulnerable to injury from the distal femoral metaphysis, particularly with a hyperextension injury. The peroneal nerve is prone to stretch injury with a varus force about the knee.
2. The spike of metaphyseal bone attached to the epiphysis on the compression side of the fracture is the Thurstan-Holland fragment.
3. On the tension side of the fracture, the periosteum is often disrupted and the metaphyseal fragment may button-hole through the quadriceps muscle.

Fig. 2 Anteroposterior (a) and lateral (b) radiographs of the right distal femur immediately following open reduction and internal fixation with two 6.5 mm cannulated partially threaded screws



4. Closed reduction may be attempted but should not be repeated or pursued in such a way to further injure the distal femoral physis (See “Sect. 7” below regarding the reduction maneuver).
5. The goal is anatomic reduction with less than a 2 mm gap as any residual displacement increases the risk of subsequent growth disturbance.
6. There may be concomitant ligamentous injuries about the knee. The knee should be examined for instability under anesthesia after achieving stable fixation and also at subsequent follow-up visits.
7. The distal femoral physis accounts for 70% of the growth of the femur and 37% of the growth of the lower extremity. It grows 9–10 mm per year until age 14 in girls and 16 in boys.
3. Reduction maneuver – the reduction maneuver should be carried out in such a way as to minimize further injury to the distal femoral physis. The deformity is exaggerated (take care with varus deformities as exaggeration may place more stretch on the peroneal nerve) and traction is applied. The compression side is aligned where the periosteum is intact and then the fracture gap is closed without grinding the physis. The order is thus pull, tip the fracture and close the separation with 90% traction and 10% leverage (Price and Herrera-Soto 2010).
4. A flap of torn periosteum may be interposed between the fracture fragments and prevent reduction. This may lead to a “squishy” feeling at the time of reduction. Although alignment may be acceptable despite interposed periosteum, the interposed soft tissue increases the risk of premature growth arrest (Phieffer et al. 2000, Chen et al. 2015).
5. A bone clamp may be used to hold the reduction. In this case, a small longitudinal incision was made laterally to facilitate the use of a bone reduction clamp to hold the reduction. The screws were inserted medially to laterally.
6. Placing two guide wires prior to drilling and placing the first screw helps prevent rotation of the fracture fragment.
7. The threaded portions of partially threaded screws should cross the fracture line in order for the screws to function in compression.
8. Bicortical fixation of the screws contributes to the stability of the construct.

6 Images During Treatment

See Figs. 2, 3, and 4.

7 Technical Pearls

1. Muscle relaxation as a component of the general anesthesia is helpful in obtaining an anatomic reduction with minimal additional injury to the physis.
2. Use of a radiolucent triangle may help allow adequate lateral visualization and may facilitate the application of longitudinal traction.

Fig. 3 Anteroposterior (a) and lateral (b) radiographs of the right knee 2.5 weeks postoperatively with early callus formation



9. If the metaphyseal fragment is not large enough for two large diameter screws (6.5 or 7.3 mm), a smaller diameter (4.5 mm) screw may be used as the proximal screw.
10. It is important to check stability after fixation with cannulated screws across the metaphysis as the metaphyseal spike may not be firmly attached to epiphysis in the setting of high energy injuries with comminution.

8 Outcome Clinical Photos and Radiographs

See Fig. 5.

9 Avoiding and Managing Problems

1. Early follow-up (about 1–2 weeks postoperatively) is recommended to check for redisplacement.
2. As mentioned above, concomitant ligamentous injury may occur in the setting of the varus and valgus stresses that cause Salter-Harris II fractures of the distal femur. The physical examination during follow-up visits should include an assessment of ligamentous stability.
3. Stiffness is not uncommon following physeal fractures involving the distal femur. Stable fixation allows earlier range of motion, and it is recommended to remove long leg casts if used by 4 weeks postoperatively. Gentle range of motion should be used to prevent stiffness,

especially active and active-assisted motion exercises. Forceful manipulation risks reinjury or additional injury. A range of motion brace that may be set to allow varying degrees of motion may be helpful as patients work on improving their motion but require continued support for ambulation.

4. The risk of growth disturbance leading to angular deformity or leg length discrepancy or both issues should be relayed to the patient and family at the time of injury as the risk is on the order of 35–50% regardless of anatomic reduction (Price and Herrera-Soto 2010).
5. Park-Harris lines are growth arrest lines that are seen on plain radiographs following a temporary slowing of growth – the dense layer of bone moves away from the physis as growth resumes. Symmetric growth of a Park-Harris line suggests resumption of normal growth, whereas an oblique growth arrest line raises concern for a growth disturbance.

When a growth arrest occurs it is often apparent by approximately 6 months postoperatively. Children with fractures involving the distal femoral physis should be followed for at least a year following the injury. Full-length standing radiographs of both lower extremities can be used to monitor leg lengths and alignment. When there is a doubt regarding premature physeal closure, an MRI may be obtained, ideally following screw removal, to evaluate the physis. MR imaging has been shown to identify a physeal bridge as early as 2 months post-injury (Ecklund and Jaramillo 2002).

Fig. 4 Anteroposterior (a) and lateral (b) radiographs of the right knee 6 weeks postoperatively with further signs of healing. At this visit, full range of motion was permitted in the hinged knee brace and the patient was weaned from crutches. Physical therapy was underway at this point and continued for range of motion exercises and quadriceps strengthening

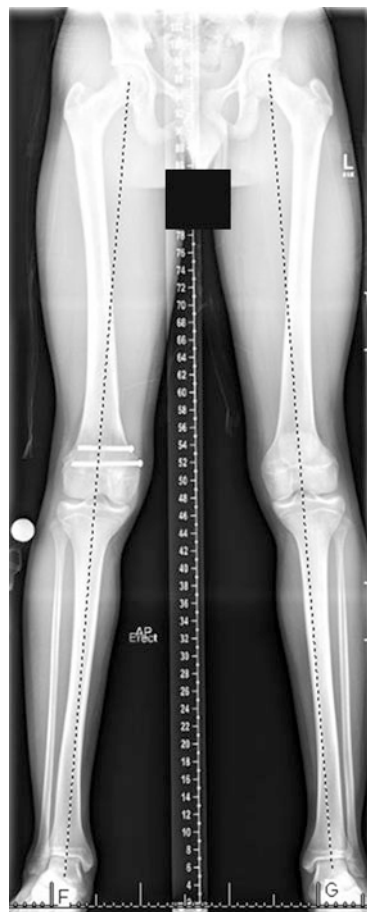


Fig. 5 Standing anteroposterior radiograph of the bilateral lower extremities approximately 1 year postoperatively demonstrating a minimal leg length discrepancy with the right leg 6 mm shorter than the left leg and 7 mm of mechanical axis deviation lateral to the femoral notch

of the right leg. The right mechanical lateral distal femoral angle (LDFA) was 88° and the left mechanical lateral distal femoral angle (LDFA) was 87° , both within normal limits.

10 Cross-References

- [Salter-Harris III Distal Femur Fracture](#)
- [Salter-Harris IV Distal Femur Fracture](#)

References and Suggested Readings

- Chen J, Abel MF, Fox MG (2015) Imaging appearance of entrapped periosteum within a distal femoral Salter-Harris II fracture. *Skeletal Radiol* 44(10):1547–1551
- Ecklund K, Jaramillo D (2002) Patterns of premature physal arrest: MR imaging of 111 children. *Am J Roentgenol* 178(4):967–972
- Phieffer LS, Meyer RA, Gruber HE et al (2000) Effect of interposed periosteum in an animal physal fracture model. *Clin Orthop Relat Res* 376:15–25
- Price CT, Herrera-Soto J (2010) Extra-articular injuries of the knee. In: Beaty JH, Kasser JR (eds) *Rockwood and Wilkins' fractures in children*, 7th edn. Lippincott Williams & Wilkins, Philadelphia
- Wall EJ, May MM (2012) Growth plate fractures of the distal femur. *J Pediatr Orthop* 32(Suppl 1):S40–S46

Salter-Harris III Distal Femur Fracture

Daniel G. Hoernschemeyer and Madeline E. Robertson

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Abstract

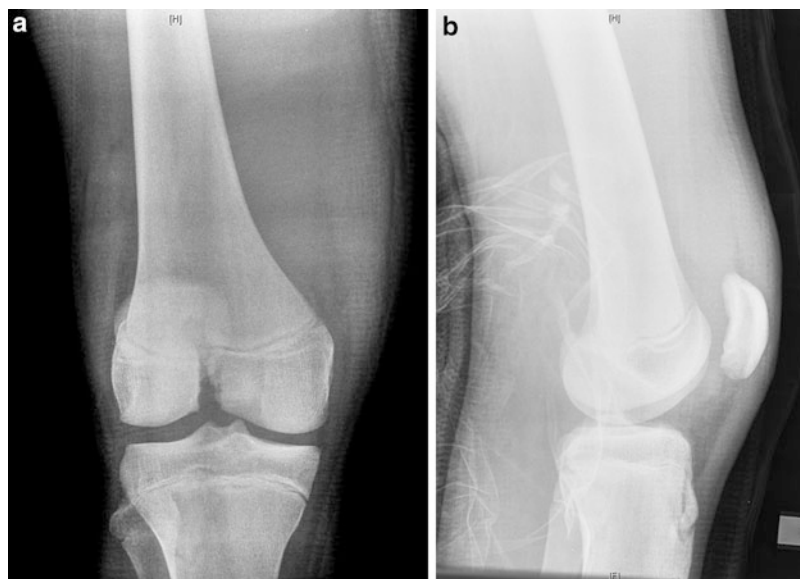
A 15-year-old male sustained a right type III Salter-Harris distal femur fracture. The 2 cm of intra-articular displacement made it necessary to proceed with open reduction and internal fixation (ORIF) of the fracture. The intra-articular extension of the fracture was reduced under direct visualization using a small arthrotomy. Subsequent X-rays showed a healed fracture after 8 weeks and the patient began full weight-bearing in a brace. The hardware was removed at 6 months.

1 Brief Clinical History

A 15-year-old male presented to the emergency room after sustaining a right Salter-Harris III distal femur fracture while playing football. The displacement of the distal femoral epiphysis was improved using conscious sedation and splinted in the emergency department (ED). The patient was later brought to the operating room. Intraoperatively, a small arthrotomy was made to better visualize the articular surface. The intra-articular fracture was reduced and stabilized with two intra-epiphyseal 6.5 mm cannulated screws. These were placed medial to lateral, getting an anatomic reduction of the joint surface. At that point, the physis was not stable with varus/valgus stress and two smooth Steinmann pins were added. The Steinmann pins were cut and a bone tamp was used to place them below the soft tissue surface. At the conclusion of

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Fig. 1 AP (a) and lateral (b) views reveal a displaced right Salter-Harris type III distal femur fracture. The X-rays show 2 cm of displacement of the lateral femoral condyle



the procedure, the patient was placed in a posterior splint and changed over to a locked hinge knee brace once the swelling went down.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Salter-Harris III distal femur fracture
2. Unstable fracture with physeal involvement
3. Intra-articular extension of the fracture with displacement
4. Determine the type of fixation to allow for early ROM

4 Treatment Strategy

The displaced lateral femoral condyle was initially managed with a closed reduction and splinting under conscious sedation in the ED. The patient was admitted for observation and elevation of the injured extremity. He was then brought to the operating room for ORIF of the fracture the following day. Our goal was to obtain an anatomic reduction of the articular surface.

While visualization of the articular surface could be performed with an arthroscopy, the concern for swelling and the low morbidity of a parapatellar arthrotomy led us to move forward with this approach. A small 4–5 cm

incision was made centered over the right knee at the level of the patellar tendon. A medial parapatellar arthrotomy was performed and the articular cartilage and fracture site was cleaned of hematoma. Using an Army/Navy retractor and a lighted suction tip, the articular surface and fracture line could be well visualized. Once the joint surface was reduced, we proceeded with intra-epiphyseal fixation given that the distal femoral physis was still open and the patient had approximately 1 year of growth remaining. The stability of the physis remained in question once we tested the knee with varus and valgus stress. At that point, we added two crossing smooth Steinmann pins. The patient was placed in a posterior splint and changed over to a locked hinge knee brace once swelling went down. We opened up the knee brace to work on ROM at 3–4 weeks given the large hemarthrosis from the trauma. The patient began full weight bearing at 6–8 weeks in the brace.

5 Basic Principles

1. Anatomic reduction must be achieved under direct visualization
2. Restore the physeal anatomy to prevent early closure of the physis (which still may occur)
3. Stable fracture fixation

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

1. All displaced Salter-Harris III fractures of the distal femur should be treated surgically with direct visualization of the intra-articular fracture using a small parapatellar arthrotomy.
2. Large periarticular clamps can be helpful in holding your intra-articular reduction while placing fixation.
3. Be sure that the fixation maximizes the stability of the distal femur fracture to allow for early ROM of the knee to prevent stiffness.
4. When placing the crossing Steinman pins, both pins can be placed from the lateral side (one antegrade and one retrograde).

8 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

9 Avoiding and Managing Problems

1. Joint stiffness after trauma and hemarthrosis – begin early ROM in a hinged knee brace
2. Early post-traumatic arthritis of the knee – be sure that your reduction is anatomic at the articular surface
3. Loss of fixation – supplement any intra-epiphyseal fixation with smooth Steinmann pins across the fracture

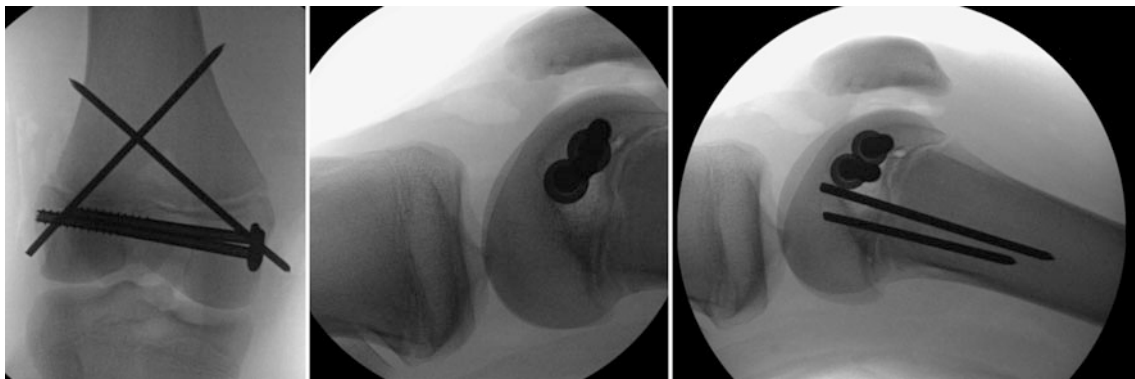


Fig. 2 Demonstrates two medially placed cannulated screws with two opposing smooth Steinmann pins. The condyle and physis have been stabilized and the reduction is maintained

Fig. 3 Radiographs at 4 weeks demonstrate proper alignment of the distal femur

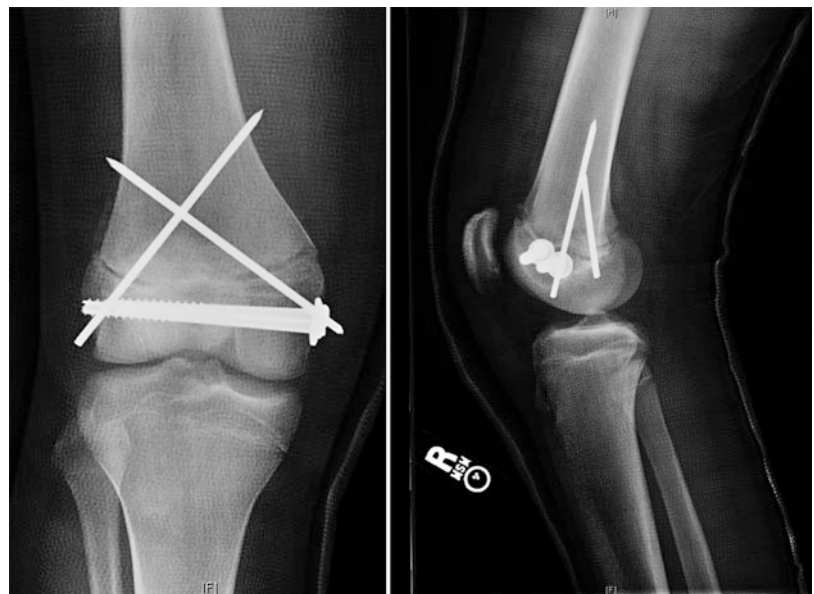


Fig. 4 Radiographs at 8 weeks show no change in alignment, with evidence of healing of the distal femoral physis



10 Cross-References

- [Salter-Harris I Fracture of the Distal Femur](#)
- [Salter-Harris II Distal Femur Fracture](#)
- [Salter-Harris IV Distal Femur Fracture](#)
- [Supracondylar Femur Fracture: Treatment with a Submuscular Plate](#)
- [Treatment of a Pediatric Open Supracondylar Femur Fracture with External Fixation](#)

References and Suggested Readings

Arkader A, Warner WC, Horn BD, Shaw RN, Wells L et al (2007) Predicting the outcome of physeal fractures of the distal femur. *J Pediatr Orthop* 27(6):703–708

Lippert WC, Owens RF, Wall EF et al (2010) Salter-Harris type III fractures of the distal femur: plain radiographs can be deceptive. *J Pediatr Orthop* 30(6):598–605

Mayer S, Albright JC, Stoneback JW et al (2015) Pediatric knee dislocations and physeal fractures about the knee. *J Am Acad Orthop Surg* 23(9):571–580

Wall E, May M et al (2012) Growth plate fractures of the distal femur. *J Pediatr Orthop* 32(Suppl 1):S40–S46

Zionts LE et al (2002) Fractures around the knee in children. *J Am Acad Orthop Surg* 10(5):345–355

Salter-Harris IV Distal Femur Fracture

Cheryl Lawing and Michael Ain

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Abstract

Salter-Harris IV fractures of the distal femur are rare but severe injuries with a rate of complete **growth arrest** of 40% and **angular deformity** 64% (i.e., partial arrest). Given the **intraarticular** nature, these fractures usually require open reduction to obtain anatomic alignment. Fixation can usually be obtained with 6.5 or 7.3 mm cannulated screws inserted through the epiphyseal fragment and metaphyseal fragments. Placement of these screws requires visualization of the “**epiphyseal triangle**” on the lateral view of the knee to ensure no intraarticular penetration. Long-term follow-up is needed given the high rates of complications.

1 Brief Clinical History

A 14-year-old boy struck by a car while riding his bicycle. He sustained a closed injury to the left distal femur and a closed left tibial shaft fracture. He presents with significant swelling around the knee and a large suprapatellar effusion. His neurovascular exam is intact and compartments are soft and compressible. There is pain and guarding with attempted examination of the knee. Radiographs show disruption through the physis with both metaphyseal and epiphyseal extensions of the fracture.

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2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

- Salter-Harris IV fracture of distal femur
- High risk for future growth arrest

4 Treatment Strategy

Anatomic reduction is key for both the epiphyseal portion of the fracture, to prevent premature arthritis, and the physal portion, to minimize the risk of **growth arrest**. There is

limited role for nonoperative treatment of these fractures, which essentially applies only to truly non-displaced, occult fractures.

5 Basic Principles

Distal femoral physal fractures are fortunately rare, comprising about 1% of all physal fractures, of which 5–19% are **Salter-Harris IV** (Edmunds and Nade 1993; Czitrom et al. 1981). There is a large male predominance in these injuries, given their traumatic nature. Eid found a 6:1 male/female ratio, with 60% being due to sports injuries, 22% due to motor vehicle collisions, and 18% due to various falls (Eid and Hafez 2002). Of historical note, this fracture was frequently caused when a child got his leg caught in the spokes of a wagon wheel, while trying to jump onto a horse-drawn



Fig. 1 Shows a Salter-Harris IV fracture. Due to the rarity of this injury, this image was borrowed from “Fractures of the Distal Femoral Physis” by Martin Herman and Brian Smith in Rockwood and Wilkins’ *Fractures in Children*, 8th edition, edited by John Flynn, David Skaggs, and Peter Waters. Wolters Kluwer, 2015

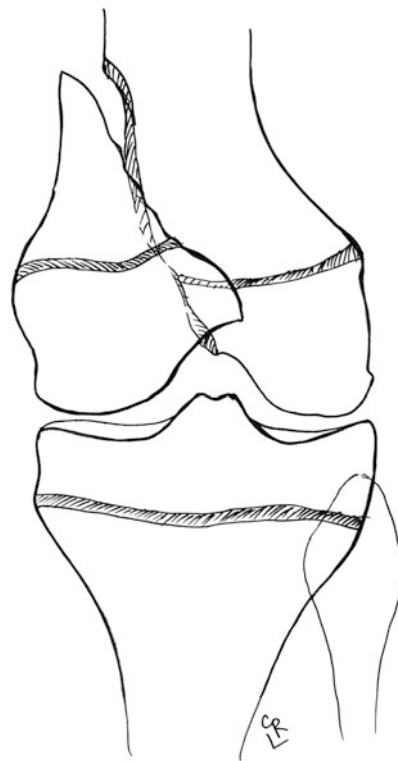


Fig. 2 Illustration of the fracture, with the fracture traversing through the metaphysis and physis, exiting in the epiphysis with intraarticular disruption

carriage, and was known as a “cartwheel” injury. This caused a combination of hyperextension and torsion. Modern injury mechanisms are usually higher energy, such as motor vehicle striking pedestrian or bicyclists, falls from heights, and sports (Edmunds and Nade 1993). Neer found that a direct blow to the lateral aspect of the femur was a common mechanism of injury, with subsequent lateral displacement of the epiphysis (Neer 1960). The side of the impact, frequently lateral, produces compression along the lateral cortex of the femur with tension that tears the periosteum and the hypertrophic zone of the physis on the opposite side of the femur. On the compression side, a triangular piece of bone frequently breaks off, known as a **Thurstan-Holland fragment**.

6 Images During Treatment

See Figs. 3, 4, and 5.



Fig. 3 AP view of the knee with epiphyseal and metaphyseal screws in place. There is persistent intercondylar step-off, however, as indicated by the white arrow

7 Technical Pearls

As with all distal femoral physeal fractures, traction is the key to reduction, in order to minimize physeal injury and the risk for **growth arrest**. The periosteum is typically intact on the side to which there is displacement, which can assist with reduction and usually prevents over-reduction. The periosteum will be disrupted on the convex side of the fracture, so there is the potential for an intervening periosteal flap that can hinder reduction. Flexing the hip can relax the quadriceps and help with anteriorly displaced fractures. Obtaining anatomic reduction of the articular surfaces is of paramount importance, and therefore a parapatellar incision for visualization of reduction is necessary. Fixation can then be performed with a 6.5 or 7.3 mm diameter cannulated screw through what Wall describes as the “**epiphyseal triangle**,” which is shown in Fig. 3 (Wall and May 2012). One must keep in mind the trapezoidal appearance of the distal femur, making it easy to have screw lengths be too long, with the



Fig. 4 Shows a lateral view. Both were taken 6 months postoperatively and show excellent consolidation across the fracture site. Rotation prevents this from being a perfect lateral and the epiphyseal triangle is difficult to visualize

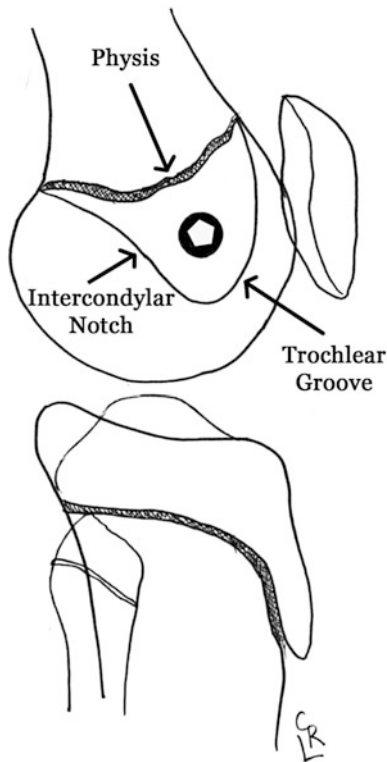


Fig. 5 The “epiphyseal triangle,” bordered by the physis, the intercondylar notch, and the trochlear groove, which guides placement of the epiphyseal screw

penetrating tips irritating surrounding soft tissues. Oblique views for assessment of screw length can minimize this complication.

8 Outcome Clinical Photos and Radiographs

See Figs. 6, 7a, b, and 8.



Fig. 6 AP view 2 years postoperatively, after removal of hardware

9 Avoiding and Managing Problems

Most important for management is continued surveillance to ensure resumption of proper growth. **Growth arrest** and **angular deformity** have been shown to occur in up to 64% of these patients (Eid and Hafez 2002). Thus, the patient should be followed until **growth arrest** lines parallel to the physis are seen. **Growth arrest** lines converging with the physis indicate presence of a **physeal bar**, which is best evaluated with a CT scan. It is wise to warn parents up front that further surgeries may be needed for growth modulation, **physeal bar** resection, or possibly even lengthening in the case of growth arrest in a young child.

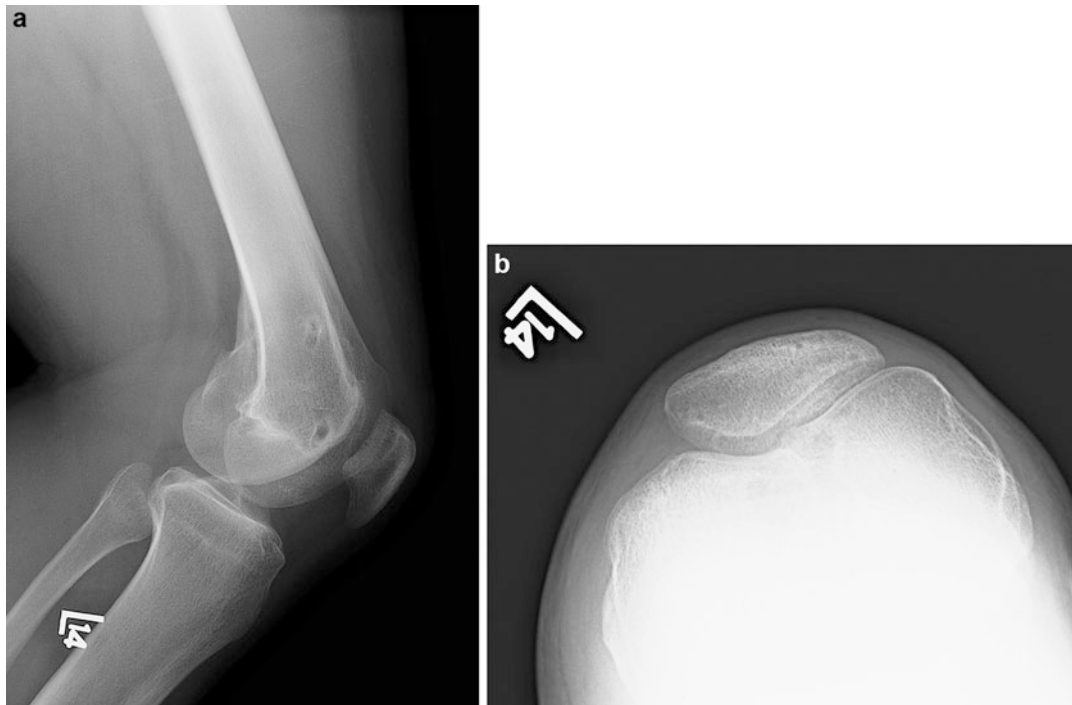


Fig. 7 Lateral view (a) and sunrise view (b). The fracture has overall healed well, though there is overgrowth of callus that is visible in (b) within the trochlear groove

Fig. 8 AP view of the femur at 2 years postoperatively. At this point, the patient is skeletally mature. There is varus of the distal femur which is likely due to initial malreduction, though asymmetric growth arrest is a very common cause of angular malalignment following this injury



10 Cross-References

- [Salter-Harris II Distal Femur Fracture](#)
- [Salter-Harris III Distal Femur Fracture](#)

References and Suggested Readings

- Czitrom AA, Salter RB, Willis RB (1981) Fractures involving the distal epiphyseal plate of the femur. *Int Orthop* 4(4):269–277
- Edmunds I, Nade S (1993) Injuries of the distal femoral growth plate and epiphysis: should open reduction be performed? *Aust N Z J Surg* 63(3):195–199
- Eid AM, Hafez MA (2002) Traumatic injuries of the distal femoral physis. Retrospective study on 151 cases. *Injury* 33:251–255
- Neer CS (1960) Separation of the lower femoral epiphysis. *Am J Surg* 99:756–761
- Wall EJ, May MM (2012) Growth plate fractures of the distal femur. *J Pediatr Orthop* 32(Suppl 1):S40–S46

Floating Knee: Combined Femoral and Tibial Fractures

Connor Green and Anthony I. Riccio

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Abstract

Ipsilateral femur and tibial shaft fractures are uncommon in the pediatric population and frequently result from high-energy mechanisms of injury. These floating knee injuries often add significant complexity to fracture management. Many are associated with concomitant visceral, thoracic, and/or head injuries that may take precedence over definitive fracture fixation especially in the setting of hemodynamic instability. Furthermore, orthopedic surgeons must often alter implant selection, patient positioning, and choice of operative table from one's usual practice when managing either fracture in isolation. This case highlights the management strategies of a 10-year-old male involved in a high velocity trauma who sustained a femoral neck fracture, an ipsilateral open distal third femoral shaft fracture, and an

ipsilateral fracture of the tibial diaphysis. We present a management strategy to maximize fixation efficiency though reduction techniques and implant choices while addressing the specific complexities of each fracture.

1 Brief Clinical History

A 10-year-old male was hit by a pickup truck at high speed while riding a motorized scooter. On presentation to the trauma bay his airway was patent, breathing was spontaneous, and vital signs were stable. Radiographs demonstrated ipsilateral femoral neck, distal femur, and tibia fractures. There was a 3 cm transverse laceration on the anterior distal thigh communicating with the fracture. Compartments of the leg were compressible. He had no nonorthopedic injuries.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

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Fig. 1 AP (a) and Lateral (b) radiographs of left femur demonstrate a distal one third femoral shaft fracture and basicervical femoral neck fracture

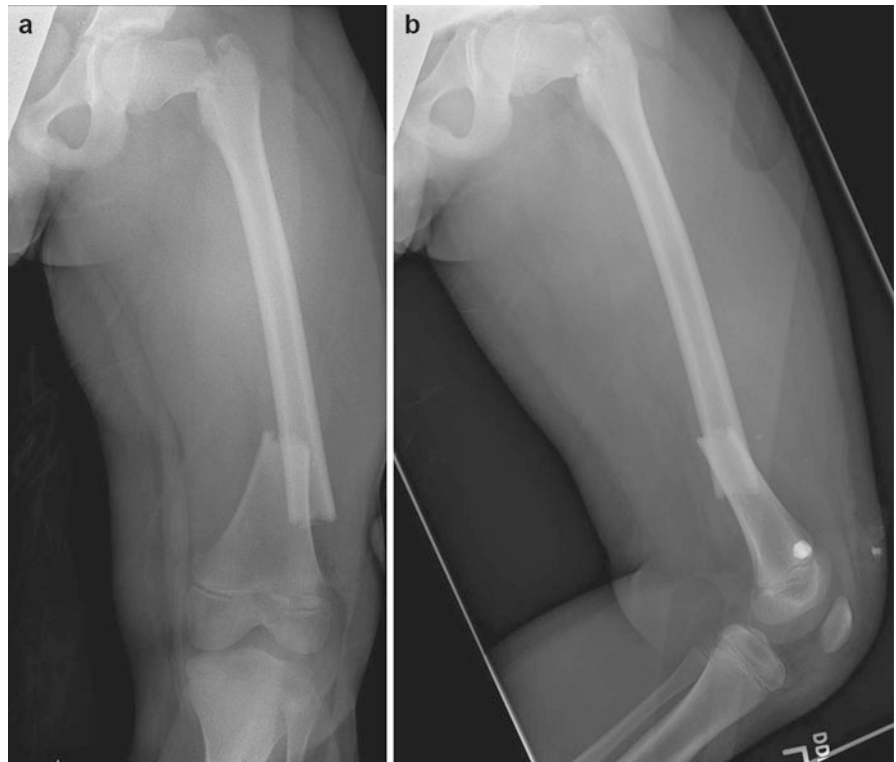


Fig. 2 AP (a) and Lateral (b) radiographs demonstrate transverse mid-diaphyseal tibia and fibular fractures

3 Preoperative Problem List

1. Left basicervical femoral neck fracture
2. Left grade III open distal one third femoral fracture at the metaphyseal-diaphyseal junction
3. Left closed mid-diaphyseal tibia and fibular fractures

4 Treatment Strategy

Treatment of this patient should begin with resuscitation and assessment for other injuries. Definitive management of the orthopedic injuries should be dictated by the patient's physiologic and hemodynamic stability (Pape and Pfeifer 2015). This patient was hemodynamically stable and without trauma to the head, spine, thorax, or abdomen. Thus, early total care was possible and indicated. Treatment was divided into open fracture management and fracture stabilization. Open fracture treatment begins in the emergency room with intravenous antibiotics, tetanus coverage, and removing only gross contaminants from the wounds before dressings are applied (British Orthopaedic Association and British Association of Plastic 2007). Definitive management in the operating room requires adequate debridement and irrigation of both the soft tissue and bone ends.

In the operating room the patient was placed supine on a fracture table. The limb was held securely during transfer to minimize movement of the femoral neck fracture. The left foot was placed in the traction boot. A coban was wrapped around the foot and up the leg extending proximal to the tibia fracture. This was wrapped tight enough to act as skin traction but loose enough to avoid compromising perfusion. This technique allowed traction to be placed on the femur while stress shielding the tibia fracture. As gentle traction was applied, intraoperative fluoroscopy was used to confirm femoral neck fracture reduction. Anatomic reduction of the femoral neck fracture was achieved by closed methods. Thorough debridement and irrigation of the open fracture with 9 l of saline was then performed. During debridement the bone ends are exposed which also allows for fracture reduction under direct vision. A trochanteric entry locked rigid cephalomedullary nail was chosen for fixation to allow for stabilization of both the femoral neck and femoral shaft fractures with a single construct (Vidyadhara and Rao 2009). The canal was over-reamed by 1.5 mm to allow easy passage of the nail and avoid distraction of the femoral neck fracture on nail insertion. To avoid iatrogenic physeal injury, nail length was selected such that the distal end was proximal to the distal femoral physis. Two proximal partially threaded interlocking screws were placed to provide compression across the femoral neck fracture and rotational control. Having achieved satisfactory debridement of the soft tissues, the open wound was closed primarily.

The coban was removed and the patient was redraped to allow for access to the tibia. The limb was left in traction. Antegrade closed intramedullary enders nailing of the tibia was then performed. Nail diameter was selected based on preoperative radiographic measurement of the tibial intramedullary canal diameter to produce an 80% canal fill. The nails were contoured to provide balanced coronal plane fixation at the fracture site and inserted from medial and lateral entry points in the tibial diaphysis distal to the proximal tibial physis.

5 Basic Principles

In this complex, high velocity injury pattern, the choice of early total care or damage control orthopaedics is dictated by the patient's physiological milieu. The basic principles of fracture management can be divided into open fracture management, reduction, and stabilization. The basic cervical femoral neck fracture requires anatomic reduction and absolute stability. In contrast, the distal femur and tibia fractures require restoration of length and alignment with relative stability fixation.

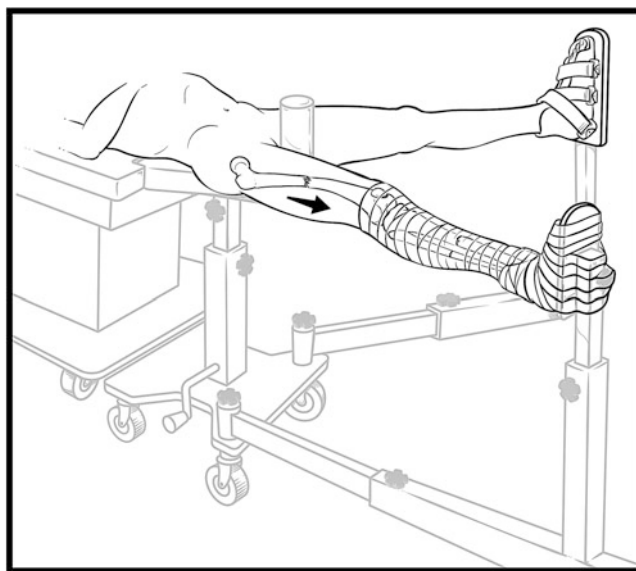


Fig. 3 Traction technique in the setting of a floating knee injury allowing for femoral fixation prior to tibial fixation. Application of Coban wrap around leg extending proximal to the tibial shaft fracture enables longitudinal femoral traction while minimizing distraction across the tibia fracture

6 Images During Treatment

See Fig. 3.

7 Technical Pearls

When using a cephalomedullary device for ipsilateral femoral neck and shaft fractures, choose an implant that allows for placement of two proximal screws. This increases stability and allows the second guide wire to remain in situ when inserting the first screw to prevent rotation of the neck fragment during screw insertion. Partially threaded proximal interlocking screws should be used to provide compression across the femoral neck fracture. Select screw lengths that allow for placement of all threads proximal to the fracture site. Stability is of paramount importance. The interlocking screws should be placed across the proximal femoral physis if the surgeon feels this will maximize construct stability.

Use a skin marker to draw out the patella. This will continually remind the surgeon of the rotational alignment of the limb which is the most common cause of malunion in femoral shaft fractures.

Drape the limb free to allow 360 access. These are difficult fractures and plans may have to change. The surgeon should not be restricted by draping.

In the absence of an associated femoral neck fracture, the order of long bone fixation in a floating knee injury is at the



Fig. 4 AP (a) and lateral (b) of the femur following cephalomedullary nailing

discretion of the treating surgeon. If fracture table traction is deemed necessary to restore femoral length, the coban technique described above may be helpful when the femur fracture is addressed first. Stabilizing the tibia initially allows for fracture table use without this technique. Alternatively, both fractures can be managed on a flat top table with manual traction. This technique is ideal for younger, smaller children, especially when flexible intramedullary nailing is used for stabilization of the femur and tibia.

8 Outcome Clinical Photos and Radiographs

See Figs. 4 and 5.

9 Avoiding and Managing Problems

Be aggressive in management of open fracture debridement and irrigation to avoid future infection. If in doubt about residual contamination or viability of the remaining tissues, a subatmospheric pressure dressing should be applied with plans for a repeat debridement in 24–48 h.

Avoid excessive movement of femoral neck during positioning which could lead to further compromise of the tenuous blood supply. Following femoral neck reduction and fixation, an arthrotomy with a Cobb elevator passed along the femoral

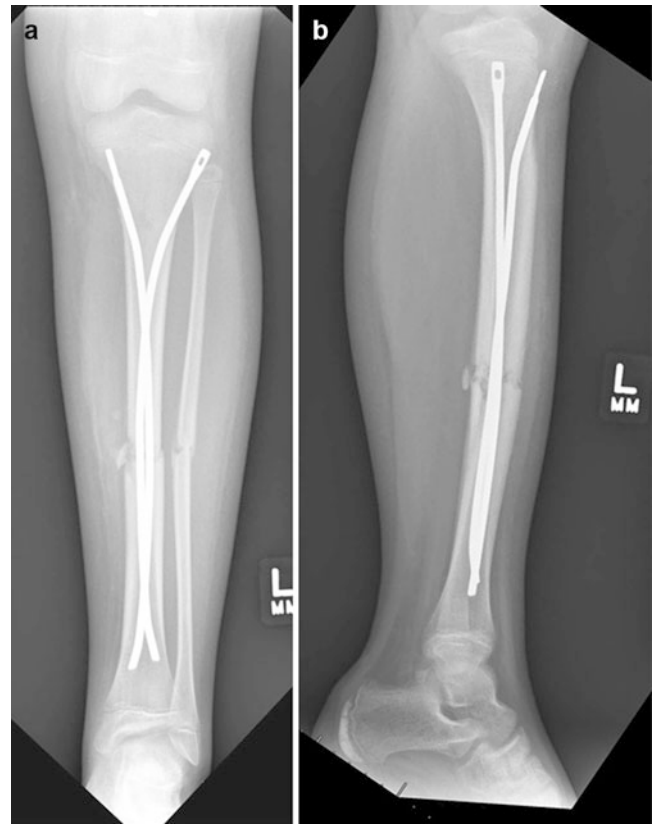


Fig. 5 AP (a) and lateral (b) postoperative tibia

neck through a small lateral incision may decompress any capsular hematoma present and decrease intracapsular pressure which could further compromise blood flow.

When performing femoral fixation first in a floating knee injury, minimize excessive tibial movement and traction to avoid inducing compartment syndrome. If spanning the tibia fracture with coban is not effective, consider placing a proximal tibial traction pin. Avoid prolonged traction and reduce traction when possible. Remain vigilant for compartment syndrome. Examine the leg compartments prior to, throughout, and after the procedure.

Be familiar with your institution's implant inventory. Know the implant sizes that are available. Children frequently have narrow intramedullary canals and proper implant length is critical to avoid iatrogenic physeal injury of the distal femur and tibia.

10 Cross-References

- ▶ [Femoral Neck Fractures in Children](#)
- ▶ [Femoral Shaft Fracture: Flexible Intramedullary Nails](#)
- ▶ [Open Femur Fracture with Soft Tissue Loss](#)
- ▶ [Tibial Shaft Fracture: Flexible Nails](#)

References and Suggested Reading

- British Orthopaedic Association and British Association of Plastic, R. a. A. S (2007) Standards for the management of open fractures of the lower limb, London, England, UK
- Pape HC, Pfeifer R (2015) Safe definitive orthopaedic surgery (SDS): repeated assessment for tapered application of Early Definitive Care and Damage Control?: an inclusive view of recent advances in polytrauma management. *Injury* 46(1):1–3
- Vidyadhara S, Rao SK (2009) Cephalomedullary nails in the management of ipsilateral neck and shaft fractures of the femur – one or two femoral neck screws? *Injury* 40(3):296–303

Patella Fracture

Bryan Tompkins

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Abstract

A 14-year-old female sustained a distal medial pole patella fracture after a direct blow to her knee while playing basketball. This required open reduction and internal fixation to provide restoration of the articular surface. The patella subsequently healed without issue but a concomitant injury to the medial patellofemoral ligament (MPFL) resulted in chronic patellar maltracking requiring operative reconstruction of the medial patellar stabilizers.

kneecap. Unable to place significant weight on her left extremity, she was taken to a local urgent care where radiographs demonstrated a distal medial patellar fracture. She was subsequently placed into a hinged knee brace and sent for further evaluation with an MRI. This demonstrated a moderately sized medial inferior patellar fracture, possible medial patellofemoral ligament (MPFL) rupture, and a contusion of the anterolateral femoral condyle. These findings suggest a possible fracture dislocation pattern of injury.

1 Brief Clinical History

While playing basketball, a 14-year-old female landed with a hard impact on her left knee. She felt an immediate pop within her knee but does not recall a dislocation of her

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, 5, and 6.

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Fig. 1 AP View. Initial injury radiographs showing a displaced osseous fragment off the inferior medial aspect of the patella



Fig. 2 Lateral View. Initial injury radiographs showing a displaced osseous fragment off the inferior medial aspect of the patella



Fig. 3 Merchant View. Initial injury radiographs showing a displaced osseous fragment off the inferior medial aspect of the patella. Displacement of the fragment is best visualized on this view

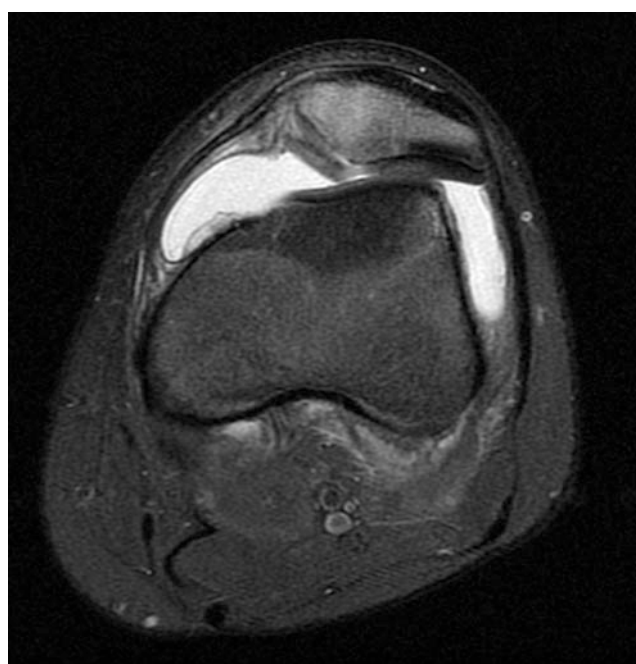


Fig. 4 Select MRI image of the patella demonstrating a possible avulsion of the MPFL off the medial aspect of the patella

3 Preoperative Problem List

1. Articular fracture of the distal medial pole of the patella
2. Likely patellar dislocation with medial patellofemoral ligament rupture

4 Treatment Strategy

The MRI showed a distal patellar pole fracture involving a significant portion of the weight-bearing surface of the patella. Since the fracture involved a portion of the articular surface, open reduction and internal fixation was required.



Fig. 5 Coronal MRI images showing a fracture that extends along the medial patella

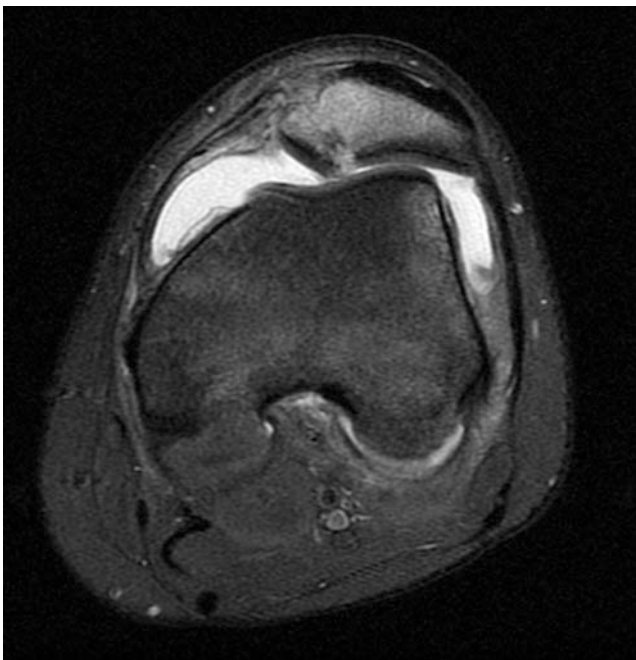


Fig. 6 Select MRI image showing a fracture that extends into the medial patellar facet

MRI findings also suggested a possible fracture dislocation mechanism of injury and concern about a possible incompetent medial patellofemoral ligament. Knee arthroscopy was planned to better delineate the degree of inter-articular injury with likely conversion to an open procedure for fixation of the articular distal pole of the patella. Small fragment screws



Fig. 7 AP radiograph following open reduction internal fixation with restoration of the joint surface

were planned for fixation. During surgery, a moderate-sized piece of articular cartilage and bone was found to be displaced off the inferior medial patella. This also involved a tear along the medial retinaculum and MPFL. Bone was anatomically reduced and secured with small screws, and suture fixation was used to primarily repair the medial retinaculum and MPFL.

5 Basic Principles

1. Patellar fractures in children are uncommon. Most are a result from either direct impact to the patella with the knee in flexion or an eccentric load during extension of the leg. Mechanically, the patella is a sesamoid bone and provides a mechanical advantage to the quadriceps during knee extension. Ossification typically occurs around age three.
2. Treatment for most displaced fractures is similar to that in adults requiring open reduction and internal fixation. A variety of techniques can be employed from screws to tension band wiring.
3. In children, a unique pattern of injury which involves an avulsed sleeve of cartilage attached to tendon or ligament can also occur. This is most commonly seen at the



Fig. 8 Lateral radiograph following open reduction internal fixation with restoration of the joint surface



Fig. 10 Lateral radiograph following implant removal 2 years after initial injury

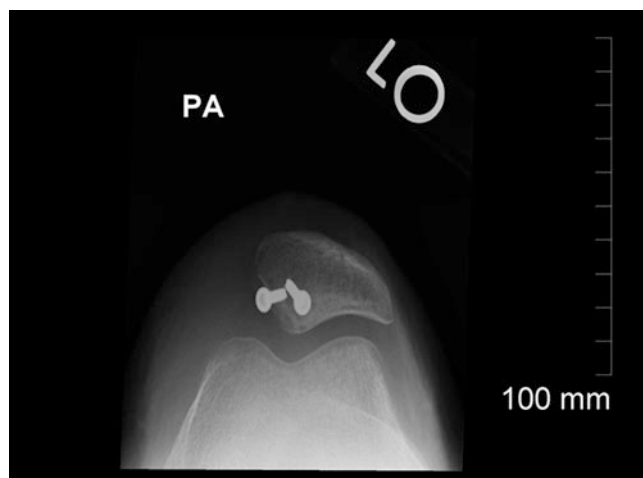


Fig. 9 Merchant radiograph following open reduction internal fixation with restoration of the joint surface

distal pole of the patella and can be difficult to evaluate on radiographs. Only a small sliver of bone may be present with the distal avulsed fragment and not easily seen on a lateral radiograph. These sleeve type injuries often involve a large articular fragment and require operative fixation to restore the joint surface.



Fig. 11 AP radiograph following implant removal 2 years after initial injury

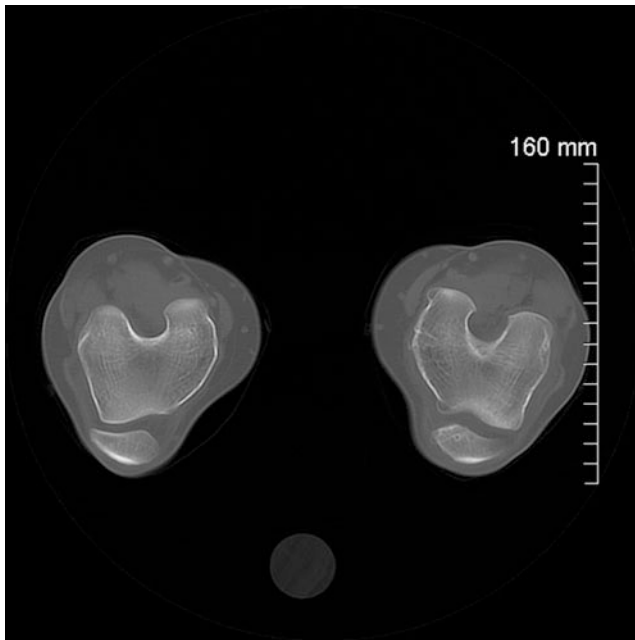


Fig. 12 Patellar tracking study (CT) showing lateral subluxation of right patella suggesting recurrent patellar instability



Fig. 14 Lateral radiograph following MPFL reconstruction with anchors in the medial patella and femur as well as a tibial tubercle medialization (Fulkerson procedure) fixed with cannulated screws



Fig. 13 AP radiograph following MPFL reconstruction with anchors in the medial patella and femur as well as a tibial tubercle medialization (Fulkerson procedure) fixed with cannulated screws

6 Images During Treatment

See Figs. 7, 8, and 9.

7 Technical Pearls

1. When the injury involves avulsion of bone and articular cartilage, there is often not sufficient bone to allow for screw fixation.
2. This avulsion pattern commonly occurs in the growing child either distally with the patella tendon or medially with the retinaculum/MPFL complex. Use of a nonabsorbable suture to repair the defect and immobilization in a cast or brace is acceptable. In other situations, the small bony avulsed fragment can be simply excised and the remaining cartilage or tendon repaired with a suture or anchor back to its base.

8 Outcome Clinical Photos and Radiographs

See Figs. 10, 11, 12, 13, and 14.

9 Avoiding and Managing Problems

1. In the younger child, fixation of the fragment is often completed with small screws or suture precluding rapid return to motion as for an adult. Prolonged immobilization in a long leg cast in extension is very well tolerated in this age group with only a small risk of significant post-operative stiffness.
2. Most patellar fractures when treated with anatomic reduction do well and carry few long-term complications.
3. Unlike in adults, AVN of the patellar following fracture is rarely observed.
4. Fractures that involve the medial aspect of the patella may also be associated with a patella dislocation. Attention to restoration of medial patellar stabilizing structures such as the MPFL is warranted. Adolescents can be rehabilitated similar to an adult with immediate motion in a hinged brace.

10 Cross-References

- [Osteochondral Fracture](#)
- [Patellar Sleeve Fracture](#)

References and Suggested Reading

- Maguire JK, Canale ST (1993) Fractures of the patella in children and adolescents. *J Pediatr Orthop* 13:567–571
- Ray JM, Hendrix J (1992) Incidence, mechanism of injury, and treatment of fractures of the patella in children. *J Trauma* 32:464–467
- Riccio A, Wilson P, Wimberly RL (2014) Tachdjian's pediatric orthopaedics: lower extremity injuries, 5th edn. Elsevier Saunders, Philadelphia, pp 1427–1430
- Zionts LE (2002) Fractures around the knee in children. *J Am Acad Orthop Surg* 10(5):345–355

Patellar Sleeve Fracture

Dennis Kramer

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Abstract

A 10-year-old male sustained a left patellar sleeve fracture after sustaining a direct blow to a flexed knee. He was taken to the operating room for open reduction internal fixation using a suture through bone technique for the sleeve fracture and associated repair of a torn medial and lateral retinaculum. Postoperatively he was placed into a cylinder cast for 4 weeks prior to starting physical therapy for knee range of motion and strengthening. The fracture healed over a 6-week period and the patient returned to full activity without complication.

1 Brief Clinical History

A 10-year-old male sustained a left patellar sleeve fracture after jumping off a diving board and hitting his flexed left knee in a direct blow on the board before falling into the pool. He had immediate pain and inability to range the injured knee. He was seen and evaluated in the emergency room where he his knee was held in flexion and a large hemarthrosis was identified. Under sedation the knee was extended and he was placed into a knee immobilizer. He was unable to extend his knee on his own. AP and lateral radiographs of the knee were obtained which confirmed a displaced left patellar sleeve fracture in association with patella alta. The patient was later taken to the operating room for open reduction and internal fixation.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

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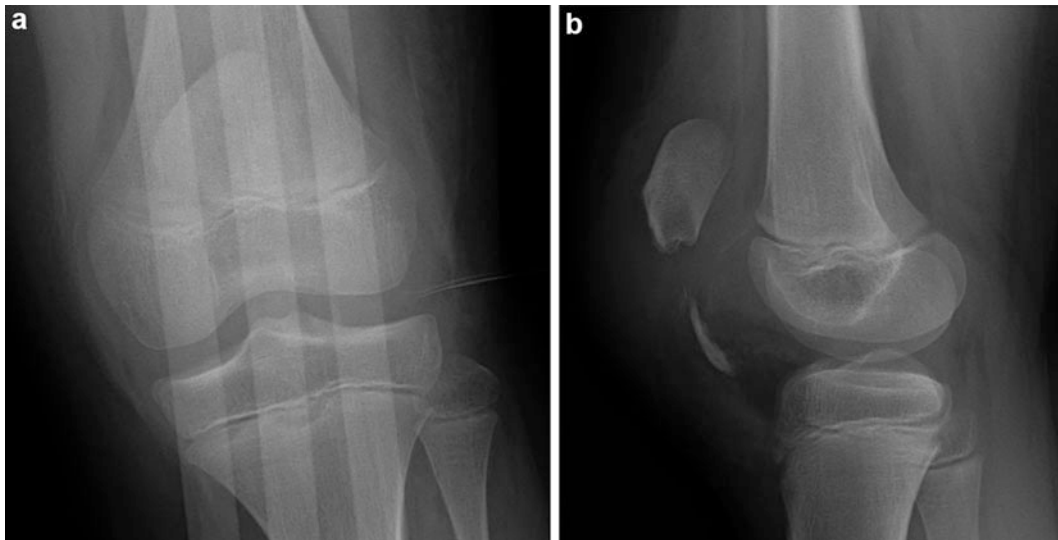


Fig. 1 AP (a) and lateral (b) views of left knee demonstrate a left patellar sleeve fracture best seen on the lateral view. The distal femoral and proximal tibial physes are open

3 Preoperative Problem List

1. Left patellar sleeve fracture
2. Possible associated injuries (knee retinacular tears, cartilage injuries to patellofemoral joint)
3. Choice of fracture fixation given limited bone in distal fragment

4 Treatment Strategy

The patient was taken to the operating room. A nonsterile thigh high tourniquet was placed and used during the case. An 8-cm midline vertical incision was made over the patella. The patella, patellar tendon, medial and lateral retinaculum were exposed to identify the zone of injury. The patellar sleeve fracture was identified as larger than it appeared on radiographs due to a large cartilaginous component, with horizontal medial and lateral retinacular tears noted. Nonabsorbable sutures were placed across the retinacular tear sites but not tied. A suture-through bone technique was then employed to repair the patellar sleeve fracture. Three vertical holes were then drilled retrograde through the proximal patellar fragment – one medial, one central, and one lateral using a 2.4 mm drill bit. Two #2 braided nonabsorbable stitches were placed into the patellar tendon/distal patellar fragment in a locking-stitch

Krakow technique so that four free suture ends (one medial strand, two central strands, one lateral strand) were present at the proximal portion of the distal fragment.

The fracture site was then reapproximated and the medial-most suture was passed retrograde through the medial tunnel in the proximal fragment using a suture passing device. Similarly, the two middle sutures were passed through the middle tunnel and the most lateral suture was passed through the lateral tunnel. Sutures were retrieved out the proximal aspect of the patellar tunnels. Tension was held on the sutures which reduced the distal fragment. The sutures were then tied to each other for secure stabilization. Finger palpation confirmed anatomic reduction of the patellar joint surface. A #1 nonabsorbable stitch was placed across the dorsal periosteal portion of the patellar fracture more proximally in a figure of eight fashion to reinforce the repair. A fluoroscopic lateral view was obtained to confirm anatomic reduction.

The medial and lateral retinacular sutures were then tied to repair the retinacular tears. The quadriceps tendon was visualized and intact. The medial retinacular repair incorporated the medial patellofemoral ligament. The knee was then lavaged and tourniquet deflated. The knee was kept in full extension for the remainder of the case. The knee incision was closed in layers with absorbable sutures. The patient was placed into a cylinder cast prior to awakening from anesthesia.



Fig. 2 Fluoroscopic lateral view obtained intraoperatively confirming reduction of the patellar sleeve fracture



Fig. 3 Lateral radiographic view obtained in cylinder cast at 2 weeks postoperatively confirming maintenance of reduction

5 Basic Principles

1. Anatomic reduction of the patellar sleeve fracture to restore congruency to the underlying patellar cartilage and restore the extensor mechanism at proper tension
2. Identify and repair associated injuries such as retinacular tears or loose fragments in the joint
3. Achieve satisfactory fixation in the distal fragment which has limited bone for purchase and allows for earlier motion following a period of immobilization

6 Images During Treatment

See Fig. 2.



Fig. 4 Lateral radiograph at 6 months postsurgery showing complete healing of the fracture

7 Technical Pearls

1. Suture fixation of the distal fragment to include the patellar tendon provides a more secure method of fixation and does not rely on the limited bone of the distal patellar pole.
2. Incorporating the periosteum of the patella in the repair provides strong reinforcement for fixation.
3. Use direct visualization (when possible), fluoroscopic imaging, and finger palpation to confirm anatomic reduction of the underlying intra-articular patellar cartilage.
4. Retinacular tears can be used to facilitate visualization of the underlying patellar cartilage if necessary.

5. Look for intra-articular chondral fragments which may be present – large osteochondral fragments should be reduced and fixated separately or incorporated into the repair.

8 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

9 Avoiding and Managing Problems

1. Younger patients can be placed into cylinder casts for immobilization for up to 4–6 weeks without significant risk of arthrofibrosis.
2. Older patients with secure fixation can be placed into a hinged knee brace with gradual increase in knee range of motion over a 6-week period.
3. Physical therapy may be necessary to regain strength and range of motion and prevent arthrofibrosis following discontinuation of immobilization.
4. Patients should be able to do a straight leg raise without an extensor lag which indicates proper tension of the extensor mechanism following treatment.
5. In certain cases, the diagnosis may be missed because the distal bony fragment is not readily discernible on radiographs – patella alta may be indicative of this injury.

6. MRI may be useful for diagnosing a sleeve fracture when the diagnosis is not clear from the clinical and plain radiographic findings.

10 Cross-References

- [Osteochondral Fracture](#)
- [Patella Fracture](#)

References and Suggested Reading

- Gupta RR, Johnson AM, Moroz L, Wells L (2006) Patellar sleeve fractures in children: a case report and review of the literature. *Am J Orthop (Belle Mead NJ)* 35(7):336–338. Review. No abstract available. PMID: 16927661
- Hunt DM, Somashekar N (2005) A review of sleeve fractures of the patella in children. *Knee* 12(1):3–7. Review

Tibial Spine Fractures: Open Treatment

Matthew Beran

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Abstract

A tibial spine fracture is a bony avulsion of the attachment of the anterior cruciate ligament. These fractures are most commonly seen in skeletally immature children and adolescents aged 8–14 years, as the bone is the point of failure with the anterior cruciate ligament (ACL) actually being stronger in resisting tensile forces than the incompletely ossified tibial plateau. These are often sports-related injuries with a mechanism similar to that of ACL tears in adults, mainly hyperextension combined with a valgus or rotational force. In up to 40% of cases, there may be associated injury to the meniscus, capsule, or collateral ligaments (LaFrance et al. 2010). Tibial spine fractures are classified by the degree of displacement (Meyers/McKeeever classification): type I is nondisplaced, type II is anterior cortical displacement with an intact posterior hinge, and type III is a completely displaced fragment. A

type IV was added later which is a comminuted fragment. The goals of treatment are to restore the integrity and function of the ACL along with the normal contour of the tibial plateau.

1 Brief Clinical History

An 11-year-old female was involved in an all-terrain vehicle (ATV) rollover. She presented to the clinic over 3 weeks out from injury. There is typically an acute traumatic event prior to the onset of presentation. While classically thought to occur following a fall onto a flexed knee from a bicycle, a majority of cases present following a noncontact sporting injury. Patients present with a large hemarthrosis. Given the extent of displacement, there may be an inability to fully extend the knee as the tibial spine is displaced anteriorly in the notch and actually blocks full extension. Given the delay from injury to surgical intervention, this patient ultimately required an open approach to reduce and fix her fracture.

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2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

Hemarthrosis of the knee
Tibial spine fracture
Three weeks from date of injury

4 Treatment Strategy

A painful hemarthrosis in a skeletally immature patient following an acute injury requires further workup. The differential includes a patellar dislocation, anterior cruciate ligament (ACL) injury (either ligament tear or bony avulsion), or other osteochondral fracture. Physical exam may be unreliable given the pain and guarding present.

Plain radiographs, particularly the lateral view, will identify a tibial spine fracture and are often sufficient to guide treatment. Magnetic resonance imaging (MRI) may be useful to identify lesions that are mainly cartilaginous as well as to identify associated meniscal tears or other chondral injuries. Some authors advocate computed tomography (CT) scans to fully evaluate the degree of displacement and comminution of the tibial spine. Regardless of the modalities utilized, the surgeon must have a full understanding of the degree of

displacement, size of the fragment, and extent of comminution to decide on the best method of treatment.

Treatment is based on the extent of displacement of the tibial spine as well as the presence of additional intra-articular pathology. The goals of surgery include an anatomic reduction of the fracture, the restoration of function of the ACL, and the maintenance of knee range of motion. Nonoperative treatment with casting or bracing in full extension to slight flexion (10–20°) is an option for type I fractures and those reducible type II fractures. Aspiration of the knee prior to reduction to evacuate the hemarthrosis may be beneficial. Patients are immobilized for 4–6 weeks prior to beginning range of motion. Nonoperative management requires close radiographic follow-up for the first couple of weeks to ensure maintenance of acceptable reduction.

All displaced fractures (type III, type IV, and irreducible type II injuries) require operative intervention. Surgery allows for the removal of barriers to reduction and anatomic fixation of the fracture. Both open and arthroscopic approaches have been described as well as the use of multiple fixation devices (screws, sutures, suture anchors, hybrid techniques). Good results have been described with both open and arthroscopic techniques and the use of screw and suture fixation (Edmonds et al. 2015; Watts et al. 2016).

The choice of approach (open vs. arthroscopic) as well as method of fixation depends largely on surgeon preference and experience as well as the character of the fracture. With the large hemarthrosis present and the need for accessory portals to facilitate reduction, these can be complicated arthroscopic cases. Surgeons uncomfortable with arthroscopy may thus elect for an open approach. Open surgery may also

Fig. 1 Images shown are the X-rays and MRI of an 11-year-old female who was involved in an ATV rollover. She presented to the clinic over 3 weeks out from injury. X-rays and MRI show injury at the tibial spine with no additional intra-articular pathology present



be preferred in cases presenting late where there is a significant fracture callous already present which must be mobilized adequately to achieve reduction. Larger bony fragments may be more amenable to screw fixation, whereas comminuted or purely cartilaginous fragments may be better treated with suture techniques.

5 Basic Principles

Incision/approach:

- As the medial tibial spine serves as the attachment site for the ACL, a medial parapatellar arthrotomy is utilized.
- Beware of the anterior horn of the medial meniscus as the arthrotomy is extended distally along the medial border of the patellar tendon.
- Lateral retraction of the patella/patellar tendon allows for direct visualization of the medial aspect of the tibial spine.

Reduction:

- Copious irrigation of the hematoma is required.
- Elevate the tibial spine fragment to completely remove all clot, cancellous bone, and other debris that may be interposed in the fracture bed.
- Carefully evaluate the anterior horn of the medial and lateral meniscus and the intermeniscal ligament as these are frequently interposed and may block reduction.
- Placing a suture around the soft tissue may facilitate retraction from the fracture site.

- Applying a posterior drawer may facilitate reduction.
- With the fragment reduced, a K-wire can be placed under direct visualization to provisionally hold the reduction.

Fixation:

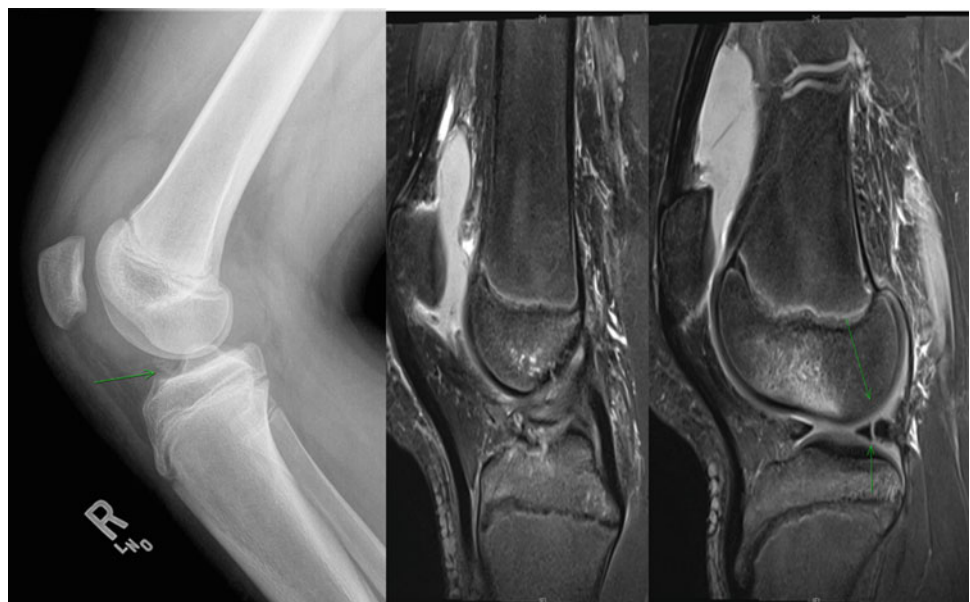
- Screws versus suture as discussed in the chapter on arthroscopic management.
- Authors have had good results using one to two 3.5 mm fully threaded cannulated screws.
- Achieving the proper angle for screw insertion may be easier with an open approach, avoiding the cartilage of the medial femoral condyle.
- Use X-ray to ensure no violation of the proximal tibial physis – usually a screw of 18–20 mm is sufficient.

6 Images During Treatment

Usually the lateral X-ray is sufficient to determine the extent of displacement of the tibial spine fracture and the need for operative intervention. If one is planning on open treatment of the fracture, preoperative MRI may be useful to assess the presence of concomitant injury to the meniscus which has been seen in up to 40% of cases. In these cases, arthroscopy may be necessary to address the associated intra-articular pathology (Fig. 2).

At the time of surgery, X-rays are necessary to confirm reduction as well as avoidance of the proximal tibial growth plate (Fig. 3).

Fig. 2 Images shown are X-rays and MRI images of a 13-year-old male that injured his knee playing basketball. MRI confirmed displacement of the tibial spine and showed a vertical tear through the posterior horn of the lateral meniscus. This patient required an arthroscopic-assisted inside-out lateral meniscus repair in addition to fixation of his tibial spine fracture



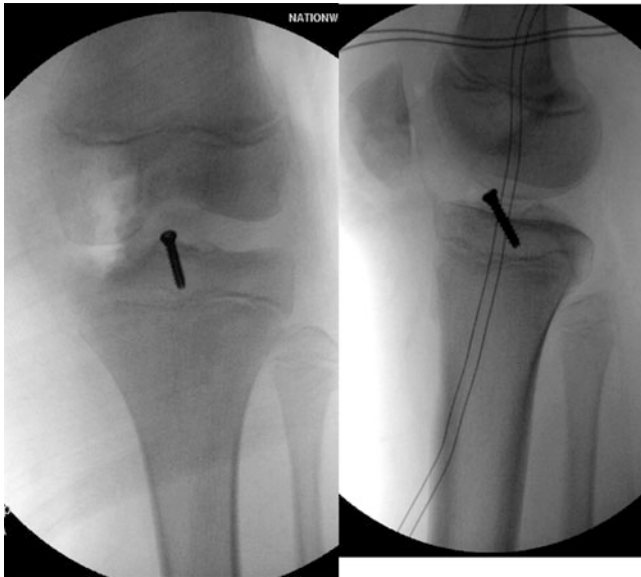


Fig. 3 Intraoperative fluoro films following open reduction and fixation of a tibial spine fracture. Fracture was fixed with a 3.5 mm cannulated screw



Fig. 4 An 11-year-old female 3 months out from open reduction and fixation of a tibial spine fracture

7 Technical Pearls

- Surgeon must be prepared for multiple fixation devices and techniques.
- Typically the size of the fragment is underestimated on plain X-rays.
- Avoid multiple attempts at obtaining purchase as this may comminute the fragment and ultimately compromise fixation.
- Anterior horn of the medial meniscus is the most common obstacle to reduction.
- Slightly recessing the fragment into the bed may better restore tension to the ACL.

8 Outcome Clinical Photos and Radiographs

See Fig. 4.

9 Avoiding and Managing Problems

Loss of motion is the most common complication following treatment of tibial spine fractures and may occur secondary to arthrofibrosis or as the result of mechanical impingement from a displaced or malunited fracture (Herman et al. 2014). Achieving solid fixation to allow early mobilization

and weight-bearing is key to minimizing the risk of arthrofibrosis. Delayed surgery (>7 days from injury) and prolonged operative times (>120 min) have been shown to be significant risk factors for arthrofibrosis (Watts et al. 2016). Management of arthrofibrosis includes careful manipulation under anesthesia or an arthroscopic lysis of adhesions. Malunited fractures that limit extension can be treated with debridement of the fragment to smoothen the bony contour and an anterior notchplasty to increase the space for the anterior edge of the tibial spine. There is often some residual laxity of the ACL itself following these injuries. Such laxity is rarely of any clinical significance.

References and Suggested Reading

- Edmonds EW, Fornari ED, Dashe J, Roocroft J, King M, Pennock A (2015) Results of displaced pediatric tibial spine fractures: a comparison between open, arthroscopic, and closed management. *J Pediatr Orthop* 35(7):651–656
- Herman MJ, Martinek MA, Abzug JM (2014) Complications of tibial eminence and diaphyseal fractures in children: prevention and treatment. *J Am Acad Orthop Surg* 22(11):730–741
- LaFrance RM, Giordano B, Goldblatt J, Voloshi I, Maloney ML (2010) Pediatric tibial eminence fractures: evaluation and management. *J Am Acad Orthop Surg* 18(7):395–405
- Watts CD, Larson AN, Milbrandt TA (2016) Open versus arthroscopic reduction for tibial eminence fracture fixation in children. *J Pediatr Orthop* 36(5):437–439

Arthroscopic Treatment of Tibial Spine Fractures

David Mandel

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Abstract

Tibial spine fractures are an avulsion of the attachment site of the anterior cruciate ligament on the tibia. They are a relatively rare type of fracture that children (ages 8–14 most commonly) may sustain. They are typically cited at less than 2% of all knee injuries in the pediatric population. The mechanism of injury is classically taught as a fall from a bike landing on a hyperflexed knee. More recent studies have supported that the mechanism of injury is similar to that of adult style anterior cruciate ligament (ACL) injury. This injury represents a failure of the chondroepiphysis. The ACL in children has a greater strength to failure than to the bone to which it is attached. It should be remembered that although the obvious injury happens at the tibial spine, a stretching injury to the anterior cruciate ligament itself can also

occur. Tibial spine fractures are classified by the Myers/McKeaver classification: type 1 is minimal displacement, type 2 is anterior half of the fractured tibial spine is elevated with intact posterior hinge, and type 3 is complete avulsion of the tibial spine. A type 4 was added later which is complete displacement with rotation.

1 Brief Clinical History

A 14-year-old young man sustained a left knee injury while playing football. He was running with the ball when a defender struck him with his helmet on the anterior knee causing a hyperextension injury. He developed immediate pain and swelling and was unable to bear weight. He went to a local emergency department where x-rays and CT scan were performed. He was then transferred to a pediatric hospital for further care.

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2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

Fig. 1 (a–d) X-rays and CT scan showing a displaced tibial spine fracture. (a) AP radiograph knee. Tibial spine fracture is seen, (b) Lateral radiograph of the knee, displacement of tibial spine fracture fragment seen, (c,d) CT scan obtained at outside hospital demonstrating displaced tibial spine fracture



3 Preoperative Problem List

Knee hemarthrosis/effusion following an injury in the pediatric population may be secondary to:

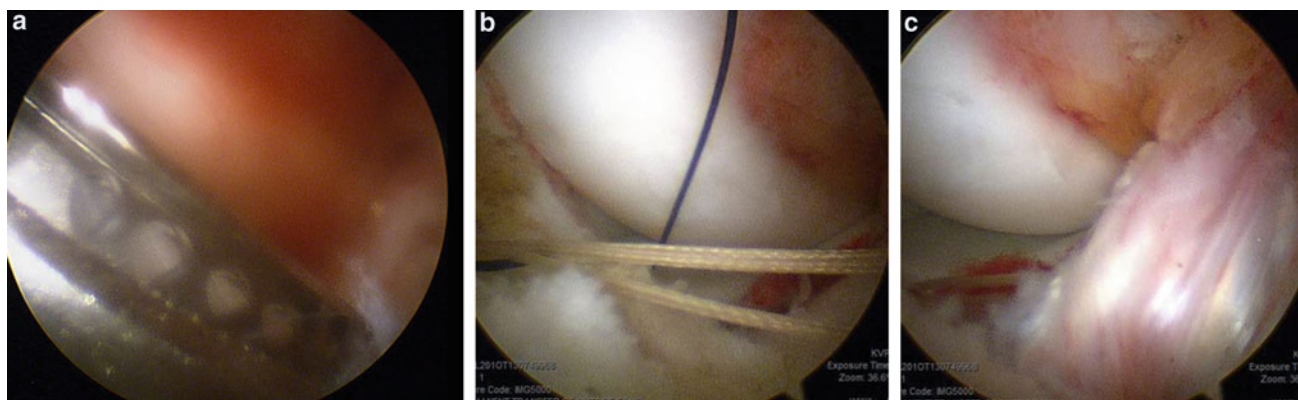


Fig. 2 Intraoperative arthroscopic images. (a) Insertion of a bioabsorbable screw into the base of the fracture fragment. (b) Passing suture through the ACL and a Hewson suture passer to be pulled through

tibial tunnel. (c) Final reduction of the fragment and retensioning of the ACL.

1. Patella dislocation
2. ACL injury
 - a. Ligament disruption
 - b. Tibial spine fracture
3. Osteochondral injury

4 Treatment Strategy

1. Nonoperative treatment
 - a. Closed reduction
 - b. Evacuation of hemarthrosis
 - c. Immobilization in 0–20 degrees of extension
 - d. Indicated for type 1 and reducible type 2 fractures
2. Operative treatment
 - a. Open reduction (ORIF) or arthroscopic reduction (ARIF)
 - b. Indicated for type 3 fractures and nonreducible type 2 fractures
3. Surgical technique
 - a. Arthroscopic reduction internal fixation
 - i. Standard arthroscopic portals (medial and lateral para-patellar portals)
 - ii. Accessory portals
 1. Central used for viewing while passing sutures through anterior lateral and medial portals. Can also be used when trying to reduce the fracture fragment
 2. High medial portal – if using cannulated screws, this portal is helpful for achieving the proper angle for screw insertion
 3. Use cannulas to prevent sutures from getting incarcerated in the soft tissues
 - iii. Debride fracture bed
 1. Remove clot, cancellous bone, or callus that may block reduction
 2. Retract entrapped meniscus/intermeniscal ligament if present
 - a. Probe or K-wire bent as a hook can be helpful in pulling meniscus/intermeniscal ligament
 - b. Passing a suture through the anterior horn of the meniscus by an outside-in technique can help reduce the meniscus and hold it out of the way
 - iv. Reduce the fracture
 1. Hold reduction with probe through accessory portal or with a K-wire or 18-gauge spinal needle
 - v. Stabilize fracture
 1. Suture
 - a. Pass one or two sutures through the base of the ACL
 - i. Can use a 25-degree curved suture lasso or scorpion type suture passer

- b. Drill two small bone tunnels in the tibial epiphysis at medial and lateral edge of the fracture bed
 - i. ACL drill guide can be helpful
- c. Pass sutures through drill holes with Hewson suture passer
 - i. Can pass sutures exiting the medial side of ACL in medial tunnel and lateral suture in lateral tunnel or pass in a X (cross over) fashion
- d. Tie sutures over bone bridge
 - i. May use button for more security of the knot
2. Screw fixation
 - a. Use accessory high medial portal
 - b. Guide wire
 - c. Cannulated screw
 - d. Take care not to violate the physis
3. Hybrid technique was selected for this case (Fig. 2)
 - a. Once fracture is reduced hold reduction with bioabsorbable screw
 - b. Once fracture is stabilized then pass sutures through ACL to re-tension the ACL and hold reduction

5 Basic Principles

1. Obtain anatomic reduction
 - a. If fragment is left proud it may lead to impingement and limited range of motion
2. Obtain stable fixation
 - a. Goal is to start early range of motion to prevent arthrofibrosis
3. Arthroscopic reduction and internal fixation may be superior to ORIF in terms of
 - a. Less morbidity
 - b. Faster rehab
 - c. Decreased pain

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

Blocks to reduction may include:

1. Intermeniscal ligament
2. Meniscus



Fig. 3 X-rays from follow-up visit demonstrating healed fracture in normal alignment

- a. 54% of the time there is entrapment of the anterior horn of either the medial or lateral meniscus
- 3. Cancellous bone
- 4. In patients with whom there is a delay in getting into the operating room, there may be clot and callus blocking the reduction

Overcoming blocks to reduction:

- 1. Use of accessory portals to pass instruments that can hook and pull the meniscus and hold it out of the way
- 2. May pass a suture through the anterior horn of the meniscus using outside-in technique and hold the meniscus out of the way for the reduction
- 3. Take time to prepare the fracture bed. Use curette to clear cancellous bone/clot/early callus from the fracture bed. If the tibial spine sits proud or remains displaced it may lead to impingement

Internal fixation with cannulated screws:

- 1. Must avoid crossing the physis
- 2. Ideal choice when large fragment is present
- 3. May be difficult to get good purchase
 - a. Epiphyseal bone is soft
 - b. Fragment may be small
- 4. Tough angle
 - a. Use accessory high medial portal off of the medial side of the patella

Internal fixation using suture:

- 1. Good for small fragments or comminuted fractures
- 2. Helps restore tension in the ACL
- 3. Near equal strength to screw fixation in lab testing
- 4. Do not cross physis with nonabsorbable sutures

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

- 1. Obtain the most rigid fixation possible to be able to start early range of motion exercises to prevent arthrofibrosis
- 2. Passing sutures through the base of the ACL helps to restore tension in the ACL while reducing the fracture. This will help to decrease residual laxity in the ACL

10 Cross-References

- [Osteochondral Fracture](#)
- [Tibial Spine Fractures: Open Treatment](#)

References and Suggested Reading

- Edmonds E, Fornari E, Dashe J, Roocroft J, King M, Pennock A (2015) Results of displaced pediatric tibial spine fractures: a comparison between open, arthroscopic, and closed management. *J Pediatr Orthop* 35:651–656
- Gans I, Baldwin K, Ganley T (2013) Treatment and management outcomes of tibial eminence fractures in pediatric patients. *Am J Sports Med* 42:1743–1750
- McLennan J (1995) Lessons learned after second-look arthroscopy in type III fractures of the tibial spine. *J Pediatr Orthop* 15:59–62
- Mitchell J, Sjostrom R, Mansour A, Irion B, Hotchkiss M, Terhune B, Carry P, Stewart J, Vidal A, Rhodes J (2015) Incidence of meniscal injury and chondral pathology in anterior tibial spine fractures of children. *J Pediatr Orthop* 35:130–135
- Shea K, Grimm N, Loar T, Wall E (2011) Bone bruises and meniscal tears on MRI in skeletally immature children with tibial eminence fractures. *J Pediatr Orthop* 31:150–152

Tibial Tuberosity Fracture: Youth Type

Stephen Hioe and Richard W. Kruse

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Abstract

Tibial tuberosity fractures are rare injuries with a reported incidence of 0.4 to 2.7%. These injuries usually occur in adolescent-aged males participating in sports, particularly basketball. Explosive quadriceps contraction against a fixed foot or rapid eccentric knee flexion are biomechanics typifying jumping activities which predispose a vulnerable tibial apophysis to avulsion injuries. A youth-type injury, as described by Pandya and colleagues, occurs in the younger adolescent and describes an isolated fracture of the ossified tip of a still-largely cartilaginous tibial tubercle. Diagnosis can be made with appropriate lateral radiographs of the knee; however, if equivocal, advanced imaging that does not preclude urgent or emergent

intervention can be considered. Surgical management involves open reduction with assessment of associated soft tissue injuries and internal fixation. While the outcomes following tibial tubercle fractures are generally excellent, this injury should always be approached with caution due to its association with complications such as compartment syndrome, vascular compromise, potential growth disturbance, and intra-articular osseous or soft tissue injuries. Close radiographic follow-up is necessary to ensure fracture stability, while longer term radiographic assessment is warranted to monitor for potential growth disturbances.

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1 Brief Clinical History

K.S. is a 13-year-old male who presented to our clinic with left knee pain after making a jump during a basketball game. Physical examination demonstrated swelling over the left anterior tibial tubercle. There was significant tenderness to palpation to this area without an appreciable knee effusion. Examination of his extensor mechanism was equivocal as it

was limited by pain. His anterior compartment was soft and compressible. Otherwise, his distal motor, sensory, and vascular examination was intact. Radiographs demonstrated a small avulsed fleck of the distal tibial apophysis (Fig. 1). An MRI of the left knee was obtained to evaluate for possible associated soft tissue injuries. Sagittal T1 weighted sequence (Fig. 2) demonstrated distal apophyseal disruption with loss of resting patellar tendon tension concordant with an avulsion injury affecting the knee extensor mechanism.

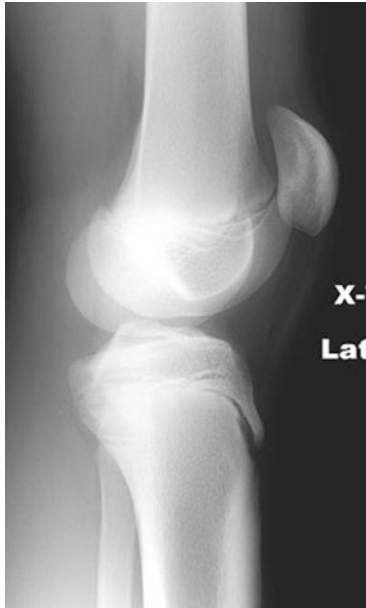


Fig. 1 Lateral radiograph of the knee demonstrating a small avulsed fleck of the distal tibial apophysis



Fig. 2 Sagittal T1 weighted image showing distal tibial apophyseal disruption with loss of resting patellar tendon tension

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Left tibial tubercle avulsion fracture; youth type
2. Possible disruption of the left patellar tendon

4 Treatment Strategy

Surgical management in this patient was aimed at correcting the amount of fracture displacement and addressing a possible disruption of the patellar tendon corroborated by our physical examination and findings of the above MRI sequence. The patient was placed in the supine position with a small bump under the ipsilateral buttock to control resting lower extremity rotation. A thigh tourniquet was applied after ensuring that we were able to obtain satisfactory AP and lateral fluoroscopic images. After the left lower extremity was prepped and draped, a longitudinal anteromedial incision was made centered over the tibial tubercle. The incision was carried down to expose the fracture as well as its proximal and distal extents. Proximally, visual confirmation of the fracture's extra-articular nature was obtained. Distally, a periosteal flap can be interposed within the fracture site and must be removed prior to attempts at manual reduction. Following this, clamp assisted reduction with the knee



Fig. 3 Postoperative lateral radiograph of the left knee showing tibial tubercle fixation with two 4.5 mm cannulated screws and washers

in full extension followed by the insertion of two Kirschner wires were used for fracture reduction. Two 4.5 mm cannulated screws over washers were then inserted for final fixation (Figs. 3 and 4). Fracture stability and reduction were carefully assessed under image intensification in two orthogonal planes and noted to be satisfactory. Inspection of the patellar tendon demonstrated a longitudinal partial disruption at its lateral insertion without extension into the retinacular tissue.

The avulsed segment was re-approximated to the remaining tendinous insertion using sutures. The patient's left lower extremity was then placed into a knee cylinder cast with instructions to weight bear as tolerated. He was transitioned to a hinged knee brace at 3 weeks postoperatively with access to 0 to 30 degrees of knee motion. At 6 weeks, the patient was allowed to fully range his knee. Postoperative radiographs at 7 months follow-up (Figs. 5 and 6) demonstrate union of the



Fig. 4 Fixation construct of the tibial tubercle as shown on an AP radiograph of the left knee



Fig. 6 7 months postoperative AP radiograph of the left knee



Fig. 5 7 months postoperative lateral radiograph of the left knee demonstrating union of the fracture site



Fig. 7 Sagittal MRI cut of the left knee demonstrating united tibial tuberosity with restoration of resting patellar tendon tension

fracture site with further proximal tibial physeal closure. An MRI examination of the left knee was repeated secondary to an atraumatic knee effusion which spontaneously resolved (Fig. 7). These images demonstrated a healed tibial tuberosity with restored patellar tendon tension as well as height.

5 Basic Principles

1. Correctly assess degree of osseous injury and whether or fracture extends into the articular surface to determine the need for advanced imaging
2. Assess for any concomitant soft tissue injuries
3. Assess patient's remaining growth potential and decide whether or not smooth Kirschner wire fixation may provide adequate fixation versus screw fixation
4. Maintain a high index of suspicion for compartment syndrome, especially the anterior compartment

6 Technical Pearls

To adequately judge maximal fracture displacement, internal rotation of the limb is required when obtaining lateral radiographs. In the face of a minimally or nondisplaced tibial tubercle injury, closely examine the knee extensor mechanism to evaluate for possible tendinous injuries or even sleeve fractures. There should be a low threshold for advanced imaging if it does not preclude urgent treatment as the sequelae of an overlooked intra-articular fracture or a fracture which extends into the posterior tibial metaphysis can lead to poor outcomes. Intraoperatively, displaced fractures should be explored to remove any interposed soft tissue prior to reduction and fixation. In youth-type tubercle fractures, consideration should also be given to fixation with smooth Kirschner wires to avoid premature physeal closure, especially, if the patient has substantial growth potential remaining. If screw fixation is used, avoid using screw sizes larger than 4.5 mm to prevent hardware associated problems.

There should be a low threshold to perform a prophylactic anterior compartment fasciotomy if prior serial neurovascular exams are concerning.

7 Outcome Clinical Photos and Radiographs

See Figs. 3, 4, 5, 6 and 7.

8 Avoiding and Managing Problems

1. Advanced imaging if suspicion for fracture extension into the joint or suspicion of associated soft tissue injury
2. Consider smooth K-wire fixation if stability is not compromised to avoid premature physeal closures
3. Patients should be monitored closely in the inpatient setting for the potential development of compartment syndrome of the lower extremity
4. Long-term radiographic follow-up to ensure no growth disturbance requiring physeal bar resection

9 Cross-References

- [Physeal Type Tibial Tuberosity Fracture in an Adolescent](#)
- [Tibial Tubercle Fracture: Teen Type](#)

References and Suggested Reading

- Brey JM, Conoley J, Canale ST et al (2012) Tibial tuberosity fractures in adolescents: is a posterior metaphyseal fracture component a predictor of complications? *J Pediatr Orthop* 32(8):561–566
- Edmonds EW, Mubarak SJ (2014) Proximal tibial physeal fractures. Rockwood and Wilkins' fractures in children, 8th edn. pp 1057–1076
- Pandya NK, Edmonds EW, Roocroft JH et al (2012) Tibial tubercle fractures: complications, classification, and the need for intra-articular assessment. *J Pediatr Orthop* 32(8):749–759

Physeal Type Tibial Tuberosity Fracture in an Adolescent

Cory Lebowitz and Richard W. Kruse

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Abstract

Fractures around the knee in the pediatric population are relatively rare. Specifically, **tibial tuberosity fractures** have an incidence ranging from 0.4% to 2.7% of all **physeal injuries**. Though uncommon, as participation in sports increases, as do the incidence of tibial tuberosity fractures. These injuries are common with activities that involve forceful quadriceps contraction during knee extension when jumping and/or aggressive passive flexion of the knee against the contracting quadriceps while landing. This mechanism, accompanied by the physiologic development of **epiphysiodesis** distally towards the

tubercle in a posterior to anterior direction, makes active adolescents mechanically vulnerable to **tibial tubercle fractures**. Pandya et al. proposed four distinct fracture patterns based off physeal closure present at the time of injury. **Physeal or Type B** involves the tibial tubercle and the epiphysis, fracturing off the metaphysis as a unit, without any intra-articular involvement. This is typically result of an injury occurring when there has not been closure of the proximal tibial physis or tubercle. Anteroposterior and lateral radiographs are obtained during the time of injury, with focus to the lateral radiograph. Acutely, patients are managed surgically, involving a closed or open reduction with internal fixation. Emphasis is on a proper diagnosis, anatomic reduction, and a strong fixation to enhance short- and long-term outcomes while avoiding complications.

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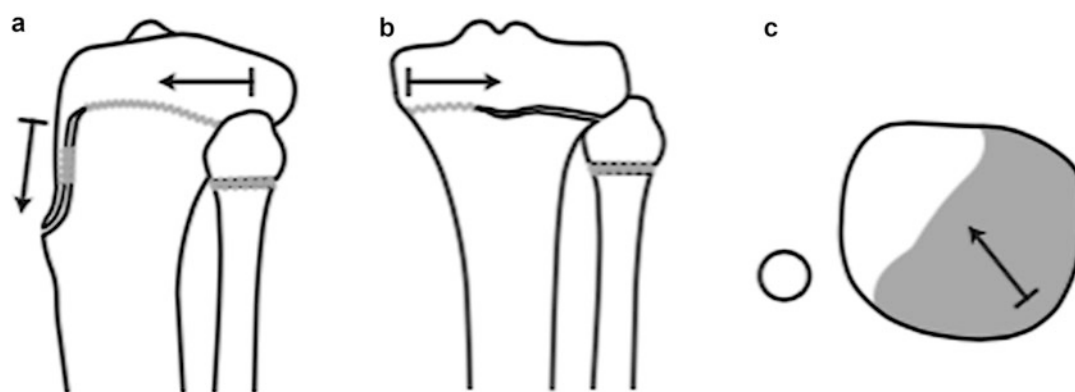


Fig. 1 Physiologic epiphysiodesis of the proximal tibial physis in the sagittal (a), coronal (b), and axial (c) plane, closing in a posterior to anterior, medial to lateral, and posteromedial to anterolateral direction,

respectively. In the sagittal plane, A, there is also a subsequent progressing of closure toward the tubercle apophysis, closing in a proximal to distal direction (Pandya et al. 2012)

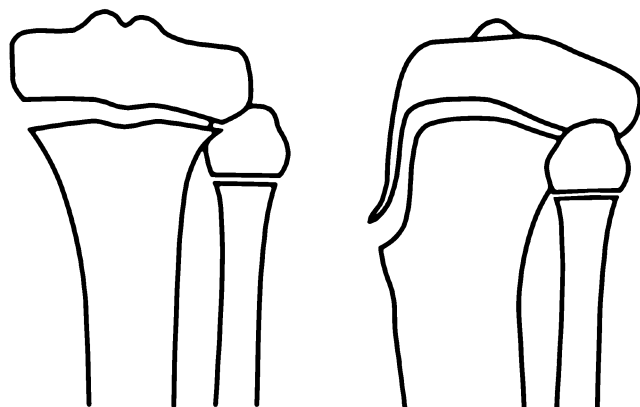


Fig. 2 Schematic diagram displaying a Pandya, Type B – Physeal Tibial Tubercle Fracture. As displayed, the physis is completely opened with an ossified tubercle. Once ossified, the tubercle and proximal tibial epiphysis pull off as a unit, as seen in both the coronal and sagittal planes (Pandya et al. 2012)

1 Brief Clinical History

Our patient was a 14-year-old, active healthy male, who presented to the emergency department with right knee pain. Just prior to coming the hospital, he jumped while playing basketball and felt immediate pain to his right knee just after landing. On exam, there was swelling and tenderness to palpation over **tibial tubercle**. Range of motion was limited secondary to pain, but was intact to motor and sensory distally. No ligamentous laxity noted. Compartments were soft and compressible with strong peripheral pulses. Radiographs of the right knee demonstrated a fracture through the entire **tibia proximal physis** with posterior **metaphyseal extension** (Figs. 1, 2 and 3).

2 Preoperative Clinical Photos and Radiographs

See Fig. 3.

3 Preoperative Problem List

1. **Physeal type tibial tubercle fracture**
2. Posterior metaphyseal extension
3. Risk of compartment syndrome
4. Need for **anatomic reduction**

4 Treatment Strategy

Patient was admitted to hospital and taken to surgery secondary to the fracture pattern displacement and entire physeal involvement. The right lower extremity was properly prepped and sterilely draped. Thereafter, a closed reduction was performed with extension of the knee. After a successful closed reduction, it was deemed appropriate to utilize percutaneous screw fixation under fluoroscopic C-arm guidance. After holding in a closed reduced position, a 1-cm incision was made over the tibial tubercle and two guide wires were placed, one more proximal in the tibial tubercle and another a bit more distal and periperpendicular to the axis of the tubercle, paying close attention to avoid posterior penetration. After appropriately measuring with a depth gauge, two 4.5 mm cannulated screws were inserted, compressing the fracture site aiding to stabilize the fracture in place. Incisions were closed and the patient was placed in a long leg cast with the knee flexed approximately 25–30°. Postoperative plain

Fig. 3 AP and lateral radiographs of a skeletally immature individual demonstrating a fracture through the entire tibia proximal physis with posterior metaphyseal extension.



Fig. 4 Postoperative AP and lateral radiographs demonstrating anatomic alignment and fixation of the proximal tibial physis and posterior metaphysis with two fully threaded 4.5 mm cannulated screws



films showed anatomic reduction of the fracture site and appropriate placement of the screws (Fig. 3). Following surgery, patient was allowed to weightbear as tolerated. At 3 weeks postoperatively, he was transitioned into a hinged knee brace with motion limited to 0–30°. At 6 weeks, he was allowed full motion in the knee and therapy was initiated for strength and range of motion.

3. **Anatomic reduction** can be achieved in a closed fashion, but necessitate being opened.

4. Operative fixation entails internal fixation with cannulated screws, maintaining anatomic reduction.

5 Basic Principles

1. The **physeal type**, with or without an associated posterior metaphyseal extension, requires not only acute care, but an adequate diagnosis.
2. Once diagnosed properly, surgical care is urgently provided with the goal of an anatomic reduction.

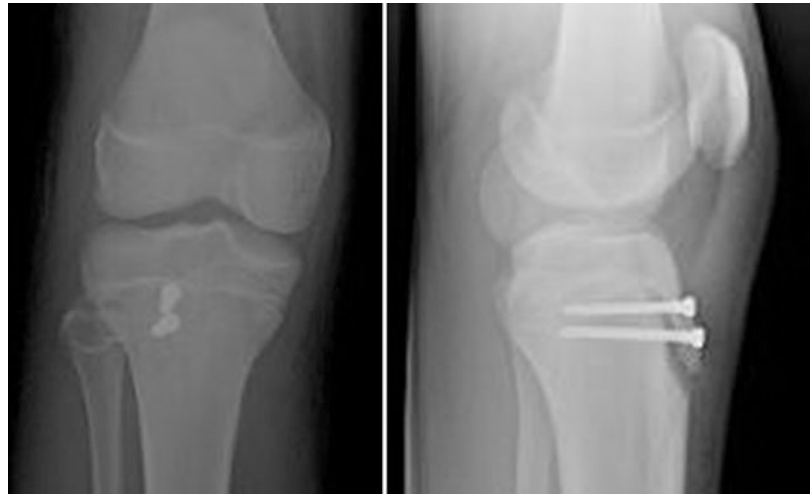
6 Images During Treatment

See Fig. 4.

7 Technical Pearls

1. Management of physeal type fractures, begins with adequate radiographs, including a true lateral.
2. **Anatomic reduction** of the **articular surface** and restoration of anatomic alignment is needed.

Fig. 5 Two months postoperative AP and lateral radiographs demonstrating continued anatomic alignment of the proximal tibial physis and posterior metaphysis, with callus formation. The two fully threaded 4.5 mm cannulated screws have maintained their position



3. Reduction can be achieved in a closed fashion; however, open reduction may need to be performed to remove interposed tissue or disimpacted bone.
4. Anatomic reduction is maintained during surgical fixation with the leg in extension, removing deforming forces from the quadriceps.
5. Use of 1 or 2 appropriate sized cannulated screws aid in stabilizing and compressing fracture site. Screws larger than 4.5 mm may be prominent and place the patient at risk for **symptomatic hardware** (Brey et al. 2012).
4. Avoiding symptomatic hardware can be achieved using headless screws with variable pitch or even countersinking the screw heads. If this does occur, removal of hardware can be performed but only clinical and radiographic union will be achieved.
5. Patients with this injury, especially those with late **epiphysiodesis**, are at risk for a **recurvatum** deformity. If clinically suspected, these patients should be monitored with serial radiographs until skeletal maturity. Patients with a **recurvatum** deformity to whom have any functional limitation can be managed with an **osteotomy** (Mencio and Marc Swiontkowski 2014).

8 Outcome Clinical Photos and Radiographs

See Fig. 5.

9 Avoiding and Managing Problems

1. **Tibial tubercle fractures**, especially the **physeal type**, are commonly noncontact injuries, but do not come without complications.
2. **Compartment syndrome** and vascular compromise can occur both preoperatively and postoperatively. If seen, emergent surgical fasciotomy must be performed.
3. Adequate reduction should be obtained with the appropriate size implants to limit **symptomatic hardware**. This can present in the form of a bursitis or tenderness to the tubercle, which when occurs can be managed with removal of hardware after union (Pretell-Mazzini et al. 2016).

10 Cross-References

- ▶ [Tibial Tubercle Fracture: Teen Type](#)
- ▶ [Tibial Tuberosity Fracture: Youth Type](#)
- ▶ [Tibial Tuberosity Fractures: Intra-articular Type](#)

References and Suggested Readings

- Brey JM, Conoley J, Canale ST, Beaty JH, Warner WC, Kelly DM, Sawyer JR (2012) Tibial tuberosity fractures in adolescents: is a posterior metaphyseal fracture component a predictor of complications? *J Pediatr Orthop* 32(6):561
- Mencio GA, Marc Swiontkowski F (2014) Fractures around the knee in children. In: Green's skeletal trauma in children, 5th edn. Elsevier Health Sciences, Philadelphia. 390436. Print
- Pandya NK, Edmonds EW, Roocroft JH, Mubarak SJ (2012) Tibial tubercle fractures: complications, classification, and the need for intraarticular assessment. *J Pediatr Orthop* 32(8):749
- Pretell-Mazzini J, Kelly DM, Sawyer JR (2016) Outcomes and complications of Tibial tubercle fractures in pediatric patients: a systemic review of the literature. *J Pediatr Orthop* 36(5):440

Tibial Tuberosity Fractures: Intra-articular Type

Elissa Dalton and Richard W. Kruse

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Abstract

A 14-year-old male presented after a twisting injury of the knee. Examination and imaging demonstrated an avulsion fracture through the entire proximal *tibial physis* with extension through the articular surface. Surgery was indicated to restore and maintain joint congruity and stability. Open reduction with cannulated screw fixation is the preferred method of fracture fixation and was performed in this case. The fracture healed uneventfully, allowing full return to activities, though the patient did return for elective screw removal.

unable to weightbear at that time. Radiographs demonstrated a *tibial tubercle fracture* with extension through the articular surface of the knee (Fig. 1). Physical examination of the knee indicated mild soft tissue swelling at the anterior knee with tenderness over the anterior tibia. Evaluation of the anterior compartment revealed no concern for compartment syndrome. Intact motor and sensory function was appreciated along with strong and symmetric peripheral pulses.

1 Brief Clinical History

A 14-year-old male presented with acute knee pain after a noncontact twisting injury. A pop was felt in the left lower extremity while attempting a karate kick and the patient was

2 Preoperative Clinical Photos and Radiographs

See Fig. 2.

3 Preoperative Problem List

1. Intra-articular avulsion fracture of the tibial tubercle
2. Small joint effusion

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Fig. 1 Anteroposterior and lateral radiographs after the injury. The extent of fracture is best appreciated on the lateral view

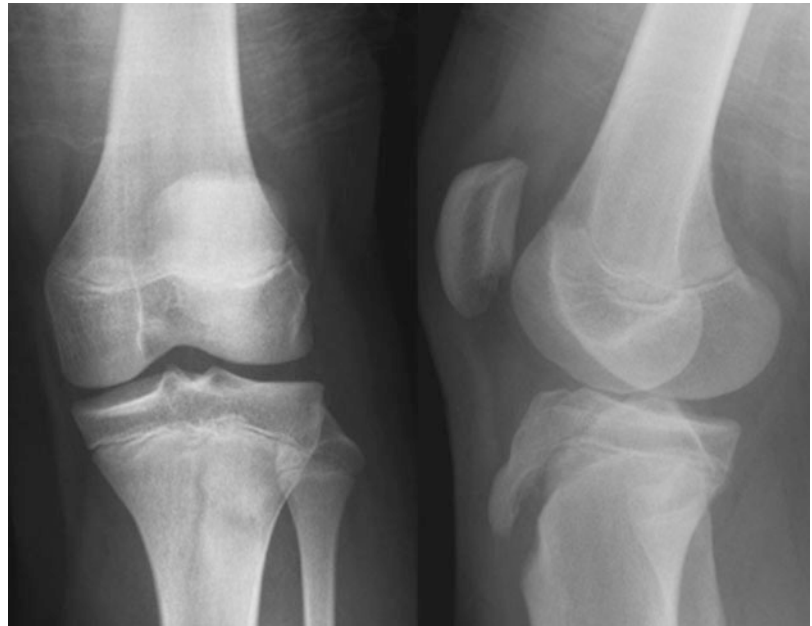
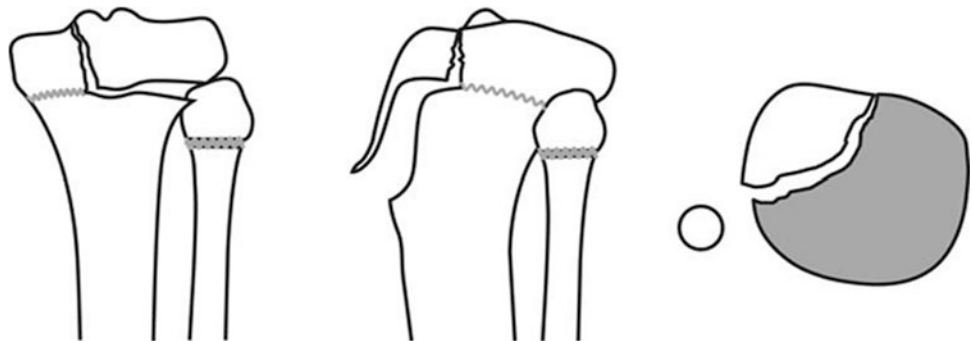


Fig. 2 Schematic diagram demonstrating intra-articular tibial tubercle fracture, with gray indicating closure of physis (Pandya et al. 2012). CT scanning may be considered to help delineate fracture pattern and plan screw placement



4 Treatment Strategy

Operative intervention was indicated to restore and maintain joint congruity and stability. After being splinted in extension, the patient's leg was elevated overnight prior to operative reduction and internal fixation. Open reduction allowed for evacuation of a small hematoma. The fracture was identified using fluoroscopy, then a reduction maneuver was performed with the knee in extension. The reduction was confirmed using anteroposterior and lateral radiographs. Three 4.5-mm lag screws with unicortical fixation were used to secure the reduction. A long leg cylinder cast was applied to immobilize the knee joint and non-weightbearing casting was maintained for 6 weeks. A Bledsoe knee brace and physical therapy helped return the patient to full activity within 3.5 months.

5 Basic Principles

Tibial tubercle fracture is a high-energy injury which most commonly occurs in males nearing skeletal maturity. The most common mechanism is during a jumping activity in basketball, particularly involving a strong quadriceps contraction. Evaluation for extent and fracture pattern of injury and additional associated pathology, i.e., injured menisci, can be assessed using preoperative CT or MRI. A 2012 study by Pandya et al. concluded that intra-articular involvement is often missed with the use of plain X-ray alone, and they recommended mandatory advanced imaging for this type of fracture. Intra-articular tibial fractures will extend into the intra-articular surface of the proximal tibia given that there has been partial closure of the proximal *tibial physis* and tubercle physis. In most cases, operative open reduction and

Fig. 3 Immediately postoperative radiographs demonstrate anatomic reduction and fixation of the tibial tubercle fragment

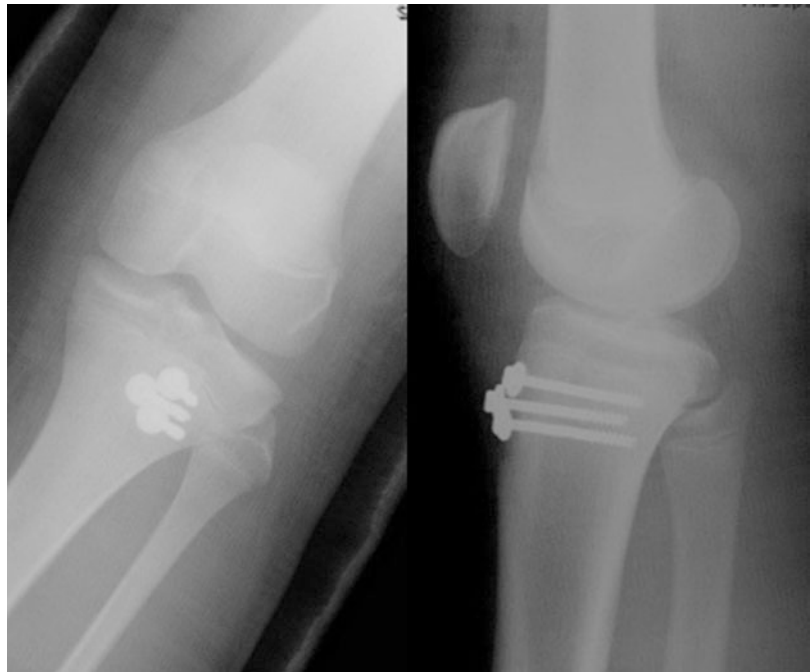
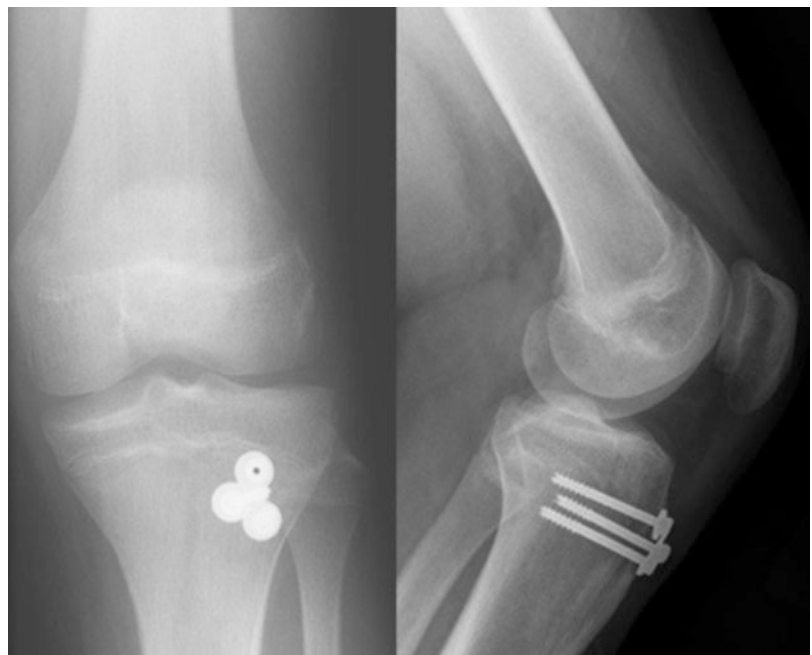


Fig. 4 The patient returned to full activity at 3.5 months after surgery. Anteroposterior and lateral knee radiographs at 6 months postoperatively demonstrate maintained anatomic position and good bone healing at the fracture site



rigid internal fixation using screws is the best course of treatment. Weightbearing is restricted for 4–6 weeks after surgery. Immobilization of the joint is accomplished using cylindrical casting for this 4–6 weeks. Physical therapy to restore motion and strength is started after cast removal. Discussion of elective screw removal with the patient should occur after recovery.

6 Technical Pearls

If *intra-articular involvement* is recognized preoperatively, arthroscopy or open arthrotomy should be utilized at the time of surgery. The operative limb should be elevated on a foam pad or stack of towels and the C-arm should be positioned on

the contralateral side with the monitor located near the foot. All interposed soft tissue should be removed from the fracture bed prior to fixation. In intra-articular injuries, the need to obtain anatomic joint reduction is essential so rigid fixation with screws is warranted. Care is needed to avoid posterior screw penetration due to the proximity of the popliteal artery and vein; bicortical fixation is typically unnecessary as good screw purchase is possible in the dense proximal tibial cancellous bone.

7 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

8 Avoiding and Managing Problems

Compartment syndrome and/or vascular compromise should be considered in all patients with tibial fracture, as it is a potentially serious complication that can occur if the fracture damages the anterior tibial recurrent artery or causes significant associated soft tissue disruption. Associated injuries, for example to menisci, cruciate ligaments, and/or joint cartilage predispose the patient to long-term joint deterioration and should be ruled out in *tibial avulsion fractures*. In the 2012 study by Pandya et al., all meniscal tears occurred with type III fractures, suggesting that fractures with articular involvement might need additional studies, such as MRI, arthroscopy, or mini-arthrotomy to better identify and evaluate associated

injuries. Complication rates are also higher in tibial tubercle fractures with *intra-articular involvement*. These complications include bursitis requiring removal of hardware, tenderness/prominence over the tibial tubercle, and refracture. Removal of hardware is indicated once the patient has reached clinical and radiographic union. Additionally, when the fracture travels into the proximal *tibial physis*, there is concern for possible future development of limb length discrepancy or a recurvatum deformity in which decreased tibial slope occurs as a result of growth arrest anteriorly as posterior growth continues. The patient should receive bilateral lower extremity films through skeletal maturity to identify these problems when suspected.

9 Cross-References

- [Physeal Type Tibial Tuberosity Fracture in an Adolescent](#)
- [Tibial Tubercle Fracture: Teen Type](#)
- [Tibial Tuberosity Fracture: Youth Type](#)

References

- Mencio GA, Swiontkowski MF (2014) Fractures around the knee in children. In: Green's skeletal trauma in children, 5th edn. Elsevier Health Sciences, p 390436. Print
- Pandya NK, Edmonds EW, Roocroft JH, Mubarak SJ (2012) Tibial tubercle fractures: complications, classification, and the need for intraarticular assessment. *J Pediatr Orthop* 32(8):749
- Pretell-Mazzini J, Kelly DM, Sawyer JR, Esteban EMA, Spence DD, Warner WC, Beaty JH (2016) Outcomes and complications of tibial tubercle fractures in pediatric patients: a systematic review of the literature. *J Pediatr Orthop* 36(5):440

Tibial Tubercle Fracture: Teen Type

Gregory T. Lichtman and Richard W. Kruse

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Abstract

Fractures of the tibial tubercle are a relatively infrequent fracture seen during adolescence, accounting for only 1% of all pediatric fractures (Mencio and Swiontkowski, Fractures around the knee in children. In: Green's skeletal trauma in children, 5th edn. Elsevier Health Sciences, Philadelphia, pp 390–436, 2014). Such fractures are typically high energy in nature and can be associated with significant soft tissue stripping, occult intra-articular injury, vascular injury, and compartment syndrome. A type D/teen-type fracture, as recently classified by Pandya et al. (J Pediatr Orthop 32(8):749–759, 2012), describes an injury only to the distal tubercle as the proximal aspect of the physis has already closed.

Surgical management of these injuries typically involves open reduction and internal fixation. Preoperatively, scrutiny of the lateral radiograph is essential to correctly classify the injury, and a low threshold for three-dimensional imaging is prudent. Key aspects to a successful operation are identification of associated injuries, removing interposed tissue from the fracture site, anatomic reduction, and solid internal fixation. Accurate diagnosis and management as well as strict adherence to surgical technique are critical to assuring a quality outcome and avoiding complications.

1 Brief Clinical History

Our patient was a 13-year-old male who presented to our emergency department with acute left knee pain after making a cut during a flag football game. Radiographs upon arrival demonstrated a teen-type avulsion fracture through the tibial tubercle apophysis with cephalad displacement (Figs. 1 and 2) (Mencio and Swiontkowski 2014; Pandya et al. 2012). On

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physical exam, a slight deformity was noted with significant swelling and ecchymosis with tenderness to palpation over the tibial tubercle. The anterior compartment of the leg was swollen but soft. He was unable to perform a straight leg raise against gravity. Motor and sensory function distally was intact, and peripheral pulses were strong and symmetric to the contralateral extremity.

2 Preoperative Clinical Photos and Radiographs

See Fig. 2.

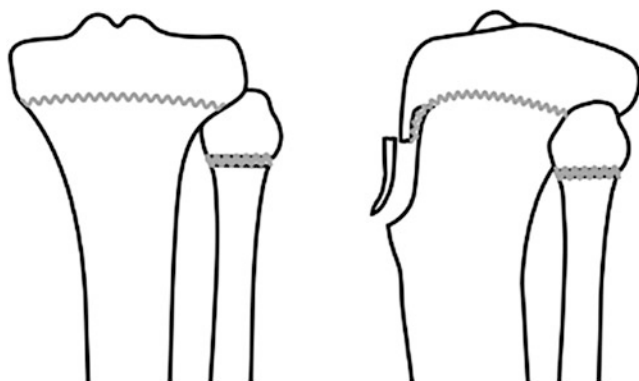


Fig. 1 An illustration demonstrating a teen-type tibial tubercle fracture as described by Pandya et al., in which the fracture occurs only through the distal tip of the tibial tubercle

Fig. 2 AP/lateral radiographs of skeletally immature individual demonstrating a fracture through the tibial tubercle apophysis with significant cephalad displacement

3 Preoperative Problem List

1. Displaced tibial tubercle fracture – teen type
2. Intra-compartmental swelling – anterior compartment

4 Treatment Strategy

Given the degree of initial displacement, the patient was taken to the operating room on an urgent basis for open reduction internal fixation. Under pneumatic tourniquet, an incision was fashioned just medial to midline to expose the fracture. The fracture was then debrided of interposed soft tissue. Upon exposure, part of the medial patellar tendon and medial retinaculum were noted to be disrupted. The leg was then extended and the fracture reduced and held manually. Reduction was then maintained with two 4.5 mm cannulated, partially threaded screws in a unicortical fashion, with care taken not to overtighten them so as to avoid iatrogenic comminution of the apophysis. A washer was utilized on the proximal screw to optimize purchase (Fig. 3). The ruptured portion of the patellar tendon and medial retinaculum were then repaired with nonabsorbable suture. Following surgery, the patient was placed in a cylinder cast and was allowed to weight bear as tolerated with his knee in extension. At 3 weeks postoperatively, he was transitioned into a hinged knee brace with motion limited to 0–30°. At 6 weeks, he was allowed full motion in the knee, and therapy was initiated for strength and range of motion. At 10 weeks following surgery, the patient



was pain free and had full knee range of motion as well as full radiographic bony union (Fig. 4).

5 Basic Principles

1. Proper identification of the injury pattern is an essential first step in managing tibial tubercle fractures.
2. The treating surgeon must maintain a high index of suspicion for occult intra-articular fractures as well as injuries to the chondral surface and/or menisci.
3. The decision of if and when to operate centers around the displacement of the fragment, the integrity of the overlying skin, and the presence or absence of compartment syndrome. No displacement should be tolerated as this will result in a compromise of the extensor mechanism of the knee.
4. Once the decision is made to intervene surgically, anatomic reduction with rigid internal fixation and early motion of the knee joint are fundamental to a successful long-term outcome.

Fig. 3 Postoperative AP/lateral radiographs demonstrating anatomic alignment and fixation of the tibial tubercle with 2 partially threaded 4.5 mm screws with a washer on the proximal screw

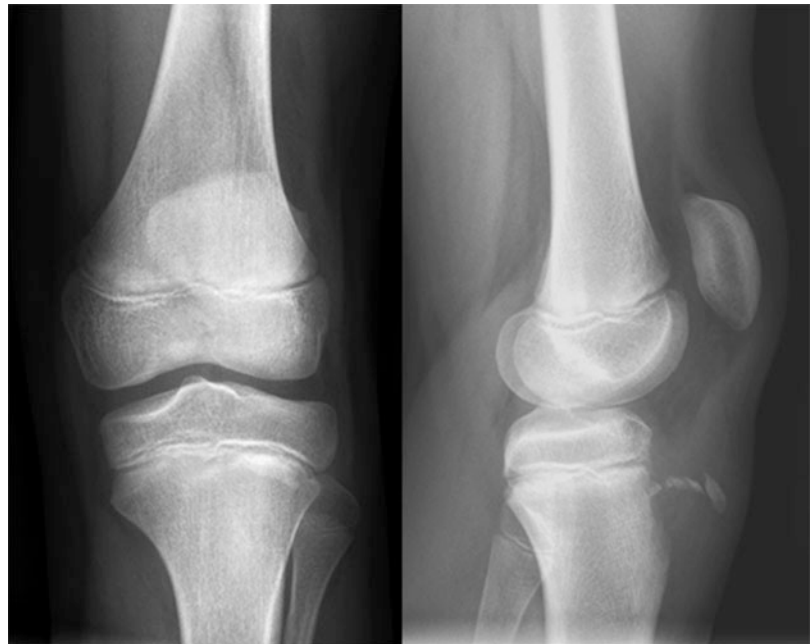
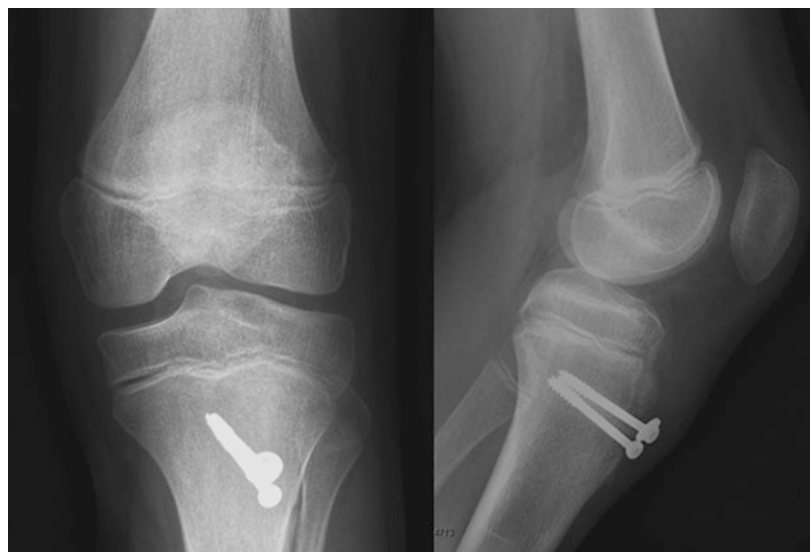


Fig. 4 AP/lateral radiographs 10 weeks postoperatively demonstrate stable internal fixation with fracture union



6 Technical Pearls

1. When surgically managing a teen-type tibial tubercle fracture, an essential first step is room setup. We recommend elevating the operative limb on a foam pad or stack of towels to allow ease of lateral imaging with the C-arm. We typically bring the machine in from the contralateral side with the monitor located near the foot.
2. The next important step is removing all interposed soft tissue from the fracture bed prior to fixation. The leg is then extended to facilitate anatomic reduction by removing the deforming force of the quadriceps muscle.
3. Fixation with screws larger than 4.5 mm in diameter should be avoided for fear of prominent hardware in the future.
4. Unicortical fixation is preferred as bicortical fixation places an unnecessary risk to the neurovascular bundle located in close proximity to the posterior tibia.
5. When poor bone stock or comminution is present on the tubercle, screws may be supplemented with washers to enhance purchase.

7 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

8 Avoiding and Managing Problems

1. Acutely, one major key to avoiding complications is recognizing the high association between even a benign-appearing tubercle fracture and compartment syndrome, which has been reported to occur with around 4% of cases (Pretell-Mazzini et al. 2016). If a compartment syndrome does occur, emergent fasciotomy should be performed.

2. The most frequent complication following screw fixation of tibial tubercle fractures is hardware prominence and irritation of overlying soft tissue, which has been reported to occur in 55.8% of cases (Pretell-Mazzini et al. 2016). The use of screw diameters of 4.5 mm or less may help avoid this. Furthermore, countersinking the screw heads or using modern headless screws with variable pitch may help avoid this. When hardware irritation does occur, removal is indicated once the patient has reached clinical and radiographic union.
3. A recurvatum deformity may occur, particularly in children with late physeal closure. If suspected, evaluation with serial radiographs is indicated until skeletal maturity, at which point osteotomy may be considered if the deformity presents a functional limitation.

9 Cross-References

- [Physeal Type Tibial Tuberosity Fracture in an Adolescent](#)
- [Tibial Tuberosity Fracture: Youth Type](#)
- [Tibial Tuberosity Fractures: Intra-articular Type](#)

References and Suggested Reading

- Mencio, Gregory A., and Marc Swiontkowski F (2014) Fractures around the knee in children. In: Green's skeletal trauma in children, 5th edn. Elsevier Health Sciences, Philadelphia, pp 390–436. Print
- Pandya NK, Edmonds EW, Roocroft JH, Mubarak SJ (2012) Tibial tubercle fractures: complications, classification, and the need for intra-articular assessment. *J Pediatr Orthop* 32(8):749–759
- Pretell-Mazzini J, Kelly DM, Sawyer JR, Esteban EMA, Spence DD, Warner WC, Beaty JH (2016) Outcomes and complications of tibial tubercle fractures in pediatric patients: a systematic review of the literature. *J Pediatr Orthop* 36(5):440–446

Proximal Tibial Metaphyseal Fracture

Bryan Tompkins

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Abstract

A 5-year female twisted her right knee while sledding sustaining a nondisplaced fracture of the proximal tibia metaphysis. This was treated in a long leg cast initially healing with good angular alignment. About 6 months after the injury, the patient developed progressive valgus in the proximal tibia, a known complication of this fracture pattern. Initially, this was treated with observation, and with time the patient showed some correction of alignment but eventually stopped improving. Guided growth was used at age 10 for correction of the deformity.

1 Brief Clinical History

A 6-year-old healthy female presents for progressive deformity of her right leg. At age 5 she sustained a right proximal tibia metaphyseal fracture during a sledding accident. She was subsequently casted for 6 weeks in a long leg cast. About 6 months after her cast was removed parents began noticing a valgus deformity in the leg. She is able to walk, run, and play without any issues such as pain or instability but parents are concerned because of the noticeable asymmetry between her legs and worried that it will continue to get worse causing problems as an adult.

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2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, 5, 6, and 7.

3 Preoperative Problem List

1. Prior history of a proximal tibia metaphyseal fracture
2. Persistent valgus deformity of the tibia

4 Treatment Strategy

The patient was initially observed to determine if the deformity would correct overtime with remaining growth alone. Serial radiographs of the lower extremity were used to measure the mechanical axis and determine changes over time. Within the first 18 months of observation the valgus deformity worsened and then gradually began to correct. After 5 years of growth following the initial fracture, the valgus deformity failed to completely correct and plateaued with the mechanical axis passing through the far lateral aspect of the knee. Since the mechanical axis was still lateral to



Fig. 2 Initial injury lateral tibia radiograph showing a nondisplaced proximal tibial metaphyseal fracture after placement into a long leg cast



Fig. 1 Initial injury AP radiograph showing a nondisplaced proximal tibial metaphyseal fracture after placement into a long leg cast



Fig. 3 AP radiograph showing healing and alignment upon cast removal 6 weeks after injury

Fig. 4 Lateral radiograph showing healing and alignment upon cast removal 6 weeks after injury



Fig. 6 Lower extremity alignment radiograph showing worsening valgus 18 months after injury



Fig. 5 AP radiograph of both knees showing progressive valgus on the right side now 6 months after initial injury

mid-knee and growth remained, guided growth using a plate hemiepiphysiodesis was planned.

5 Basic Principles

Most proximal tibial metaphyseal fractures occur in the 3–6-year age group as a result of a torsion force to the medial aspect of the knee. Most often these are nondisplaced or a torus type pattern of injury. However, higher energy fractures with complete displacement can occur, and in these instances the provider must be observant of neurovascular injury and compartment syndrome. Patients typically present with pain localized to the proximal tibia with associated finding on radiographs of the area. Special imaging is rarely required. Most fractures can be treated in a standard long leg cast for 4–6 weeks or until healed. Rarely is operative fixation required. The most common problem associated with this fracture pattern is development of a valgus deformity of the



Fig. 7 Lower extremity alignment radiograph showing some improvement of tibia valgus 5 years after injury but with little change in alignment over the last couple of years

tibia that progresses within 6–24 months after injury. This progressive valgus deformity is commonly referred to as Cozen's phenomenon.

6 Images During Treatment

See Figs. 8 and 9.

7 Technical Pearls

The majority of patients that develop a valgus tibial deformity do not require treatment as they will self-correct with growth alone. However, a small percentage of patients do continue to progress, who do not correct completely with time or have significant mechanical symptoms that require intervention. The surgeon should avoid the desire to perform a proximal tibia osteotomy in a skeletally immature child as this carries some risk for compartment syndrome and the



Fig. 8 Intraoperative AP fluoroscopy showing placement of plate and screws (8-plate) along the proximal medial tibial physis for guided growth



Fig. 9 Intraoperative lateral fluoroscopy showing placement of plate and screws (8-plate) along the proximal medial tibial physis for guided growth

osteotomy itself might restart the process and result in recurrent valgus deformity. In this scenario, guided growth is very effective, performing a temporary medial hemiepiphysiodesis with plate and screws.



Fig. 10 Now at age 10, lower extremity alignment radiograph showing correction of mechanical axis on the right 18 months after the start of guided growth. Eventually the patient returned to the operating room for removal of implants



Fig. 11 Lower extremity alignment radiograph showing slight rebound of valgus after plate removal but overall all good maintenance of a near normal mechanical axis

8 Outcome Clinical Photos and Radiographs

See Figs. 10 and 11.

9 Avoiding and Managing Problems

Since the initial presentation of these fractures are fairly innocuous, it is important to discuss with the patient and parents the possibility of development of a valgus deformity after treatment of the initial injury. This will avoid confrontation when the complication does occur, making treatment easier. The majority of patients that develop valgus deformity will correct their alignment with growth alone. However, this requires diligence on behalf of the provider and discussion with the family that initial observation alone is the best course of action. Close and routine follow-up may be required for some families.

10 Cross-References

- ▶ [Physeal Type Tibial Tuberosity Fracture in an Adolescent](#)
- ▶ [Tibial Tubercle Fracture: Teen Type](#)
- ▶ [Tibial Tuberosity Fracture: Youth Type](#)
- ▶ [Tibial Tuberosity Fractures: Intra-articular Type](#)

References and Suggested Reading

- Jackson DW, Cozen L (1971) Genu valgum as a complication of proximal tibial metaphyseal fractures in children. *J Bone Joint Surg Am* 53(8):1572–1578
- McCarthy JJ, Kim DH, Eilert RE (1998) Posttraumatic genu valgum: operative versus nonoperative treatment. *J Pediatr Orthop* 18(4): 518–521
- Riccio A, Wilson P, Wimberly RL (2014) Tachdjian's pediatric orthopaedics: lower extremity injuries, 5th edn. Elsevier Saunders, Philadelphia, pp 1459–1465
- Stevens PM, Pease F (2006) Hemiepiphysiodesis for posttraumatic tibial valgus. *J Pediatr Orthop* 26(3):385–392

Tibial Shaft Fracture: Flexible Nails

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Abstract

A 12-year-old boy sustained an injury to his left leg due to a car accident. Distal neurovascular status of the left lower extremity was intact and the extremity had no open wounds. On radiographic evaluation he was found to have a mid-shaft oblique tibia fracture, with malrotation and shortening. Under fluoroscopy an attempt was made to reduce the fracture; however, the fracture was found to be unstable. Subsequently the patient was taken to the operative room for operative intervention requiring internal stabilization with flexible nailing. He was placed nonweight bearing in a short leg cast for 3 weeks. After radiographs showed adequate healing, he was allowed to weight bear as tolerated for 3 weeks in a camboot. At 6 weeks from

surgery with complete union present on radiographs and no pain, he was allowed to fully weight bear as tolerated. Six weeks later, he was evaluated clinically and found to be pain free with full motion; therefore, he was allowed to return to all activities with no restrictions. At 10 months postoperatively, he elected for intramedullary nail removal which was completed without any complications.

1 Brief Clinical History

A 12-year-old boy was involved in a car accident while he was riding his bicycle. In the emergency room, he was awake, alert, and oriented. He had multiple lacerations on his face, and he was complaining of pain in his left leg. The leg was swollen and deformed with no open wounds. The left foot was warm and well perfused with no signs of neurologic deficits.

Radiographic evaluation of the cervical spine, chest, and pelvis ruled out any injury to these regions. Computed tomography of the head and neck did not show any abnormalities. Left leg radiographs showed a mid-shaft oblique tibial fracture, with malrotation and shortening. The fibula was intact.

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Since the patient was in a stable condition, and after the facial lacerations were addressed, it was decided to proceed with the orthopedic management of the left tibial fracture. Treatment options were discussed with the patient and his family.

2 Preoperative Imaging

See Fig. 1.

3 Preoperative Problem List

1. Several lacerations on the face (imaging ruled out bony head injury or brain injury)
2. Left lower leg pain, swelling, and deformity
3. Left tibial shaft oblique fracture

4 Treatment Strategy

Most pediatric tibial shaft fractures can be managed non-operatively with closed reduction and cast immobilization. However, surgery is indicated when the fracture is irreducible, unstable, open with soft tissue injury, or associated with multiple injuries. Surgical fixation is also indicated when

residual deformity, following an attempt of closed reduction, is unacceptable such as a sagittal angulation of more than 10°, coronal angulation of more than 5°, shortening of more than 1 cm, or malrotation.

In our patient, an attempt was made to reduce the fracture under fluoroscopy; however, the fracture was unstable and the decision was made to proceed with surgical internal fixation. Multiple options are available to surgically treat pediatric tibial fractures such as pins and plaster, external fixation, intramedullary flexible or rigid nailing, and open reduction with plate fixation. Flexible intramedullary nails are optimal for middle third length stable tibial shaft fractures in children with open proximal tibial physis. Flexible nailing is a minimally invasive surgery, and its advantages also include shorter hospital stay, low infection rate, early weight bearing, faster healing, improved functional outcomes, and low refracture rate as compared to other fixation methods (Gordon et al. 2007; Goodbody et al. 2016). Unlike the femoral shaft fractures, the use of titanium elastic nails for tibial shaft fractures seem not to be precluded in older and heavier patients (Goodbody et al. 2016).

Postoperatively, the literature suggests immobilization for 2–3 weeks in a splint or short leg cast. When radiographs show signs of union, as defined by bridging callus formation of three cortices on the anteroposterior and lateral views, weight bearing can be allowed. The goal usually is for full weight bearing at 6–8 weeks

Fig. 1 (a) Anteroposterior radiograph of the left leg showing an oblique fracture of the tibial shaft. (b) Lateral radiograph of the left leg showing an oblique fracture of the tibial shaft. (c) Lateral radiograph of the left knee to rule out associated knee injuries





Fig. 2 (a, b) Immediate postoperative anteroposterior radiograph of the left tibia

postoperatively. If there is evidence of progressive malalignment, correction should be performed with cast wedging. Delayed healing with hypertrophic bone formation remains a risk in transverse, length stable, fractures that might need prolonged immobilization or sometimes surgical interventions to obtain final union (Goodbody et al. 2016). Elective nail removal is recommended around 6–12 months after surgery.

5 Basic Principles

1. General evaluation of the patient is necessary to rule out injuries to other body systems.
2. Neurovascular examination of the extremity is essential.
3. It is important to keep a high level of suspicion for compartment syndrome and to check that the leg compartments are soft with no tension.
4. The knee and ankle are evaluated for any possible injuries.
5. Temporary stabilization with a splint makes the patient comfortable during the preoperative assessment.



Fig. 3 (a, b) Anteroposterior radiographs of the left tibia, 10 months after surgery

6 Technical Pearls

1. The extremity is prepped and draped in an aseptic environment with the patient in supine position.
2. The isthmus of the medullary canal is measured, and two, equally sized nails are chosen to fill 80% of the canal (Pandya 2016).
3. Before inserting the nails, gently bend them so that the apex of each will be at the level of the fracture. This level can be determined using fluoroscopy.
4. Two incisions are made anteriorly on the proximal medial and lateral metaphysis 2 cm distal to the proximal tibial physis (Pandya 2016).
5. The nails are then advanced to the fracture site.
6. Open reduction is considered after failed attempts of closed reduction.
7. After reduction the nails are further advanced to traverse the fracture site into the distal metaphysis.
8. The nails can assist in obtaining reduction.

9. Proximally, nails should be cut short to prevent soft tissue irritation (Pandya 2016).

7 Outcome Radiographs

See Figs. 2 and 3.

8 Avoiding and Managing Problems

1. A minimum nail to medullary canal diameter ratio of 40% for each nail should be achieved to avoid complications (Lascombes et al. 2013).
2. Avoid multiple failed passes of the nail which may injure the soft tissue compartments and cause compartment syndrome. Do not hesitate to make a small incision to facilitate the reduction of the fracture.
3. As the nails are advanced into the distal metaphysis, the tips are directed posteriorly to prevent recurvatum (Pandya 2016).
4. For length or rotationally unstable fractures, a temporary external fixator can be placed around the flexible nails to hold the alignment until callus is present. The fixator can then be removed after 3–4 weeks.
5. Delayed union or hypertrophic nonunion may indicate too much motion at the fracture site. More stable fixation with a plate or external fixator may be necessary to achieve full union.

6. Most patients are placed in a short-leg cast and immobilized non-weight bearing for 4–6 weeks postoperatively, then allowed walking when adequate callus is viewed at the fracture site. Fractures are typically considered united when tricortical callus is visible on the radiographs and no tenderness at the fracture site on clinical examination.

9 Cross-References

- [Compartment Syndrome of the Leg](#)

Suggested Reading

- Goodbody CM, Lee RJ, Flynn JM, Sankar WN (2016) Titanium elastic nailing for pediatric tibia fracture: do older, heavier kids do worse? *J Pediatr Orthop* 36(5):472–477
- Gordon JE, Gregush RV, Schoenecker PL, Dobbs MB, Luhmann SJ (2007) Complications after titanium elastic nailing of pediatric tibial fractures. *J Pediatr Orthop* 27(4):442–446
- Lascombes P, Huber H, Fay R, Popkov D, Haumont T, Journeau P (2013) Flexible intramedullary nailing in children: nail to medullary canal diameters optimal ratio. *J Pediatr Orthop* 33(4):403–408
- Pandya NK (2016) Flexible intramedullary nailing of unstable and/or open tibia shaft fractures in the pediatric population. *J Pediatr Orthop* 36(Suppl 1):S19–S23

Tibial Shaft Fracture: Plating

Megan Young

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Abstract

A 12-year-old female pedestrian struck presented with an isolated injury to the right lower leg. Examination revealed a 1 cm open wound on the medial aspect of the leg directly over the fracture site consistent with a Grade 1 open fracture of the tibial shaft. Imaging confirmed a transverse fracture of the distal tibia and fibula shaft. Further inspection of the X-rays revealed an associated medial malleolus fracture. The open fracture was treated with prompt IV antibiotics and formal irrigation and debridement of the proximal and distal bone fragments. The transverse fracture pattern, distal shaft location, clean non-contaminated open wound, and exposure created to debride the bone factored in the decision to achieve absolute stability with internal compression plating technique. Alternative options for reduction and stabilization of a tibial shaft fracture in a skeletally immature child include

casting, external fixation, and flexible intramedullary nails. The ipsilateral non-displaced medial malleolus fracture was managed nonoperatively in a cast. Postoperatively the patient remained non-weight bearing for 6 weeks. Both fractures healed uneventfully in anatomic alignment. The patient returned to unrestricted activity without pain.

1 Brief Clinical History

A 12-year-old female presented after being struck by a low-speed moving vehicle. Initial evaluation revealed an obvious deformity and instability of the right lower extremity with a 1 cm open wound on the medial aspect of the distal third of the lower leg. No gross contamination was appreciated externally, and the neurovascular examination was normal. The anterior, lateral, and superficial posterior compartments were soft on presentation. The knee was without effusion or joint line tenderness, but pain was elicited to palpation of the medial ankle. Plain radiographs confirmed a

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transverse distal shaft fracture involving the tibia and fibula at the same level. On further inspection a non-displaced fracture of the medial malleolus was also identified. The patient received IV ancef within 3 h of the injury per open fracture management protocol. Surgery was indicated to debride and stabilize the open tibial fracture.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Open wound 1 cm/open fracture
2. Unstable distal third tibia and fibula shaft fracture
3. Ipsilateral medial malleolus fracture

4 Treatment Strategy

Following extension of the open wound, intraoperative inspection, and debridement of the proximal and distal fracture ends, treatment options for restoring and maintaining alignment include casting, external fixation, intramedullary flexible nails, and internal plate fixation. The exposure facilitated direct anatomic reduction of the tibia. The simple transverse fracture pattern with a small wedge fragment was

amenable to standard compression plating with a six-hole dynamic compression plate. This fixation strategy provides absolute stability for direct bone healing and avoids potential loss of reduction in a cast or with flexible intramedullary nails given the distal location of the fracture. The clean, non-contaminated wound and adequate soft tissue coverage obviate the need for prolonged external fixation and known complications of pin infections, delayed union, and refracture.

5 Basic Principles

1. Based on mechanism of injury, consultation with general surgery trauma team for complete assessment of potential non-orthopedic injuries may be warranted.
2. A thorough orthopedic examination of all extremities and the spine is important to exclude associated injuries, especially the joint above and below the known open fracture.
3. Preoperative imaging with plain radiographs to include orthogonal views of the entire tibia and fibula is generally sufficient to visualize the fracture pattern and develop a plan for fixation. Dedicated imaging of the knee or ankle joint should be considered if incompletely evaluated on the full length tibial films or indicated based on clinical suspicion for associated ipsilateral injury.
4. Prompt initiation of intravenous antibiotics for open fracture management within 3 h and timely debridement of the open fracture site reduce potential complications of infection.

Fig. 1 Anteroposterior (a) and lateral (b) radiographs of the right tibia show a transverse fracture of the tibia and fibula near the diaphyseal-metaphyseal junction with a small wedge fragment. An associated fracture involving the anterior colliculus of the medial malleolus is best appreciated on the lateral image



5. The optimal fixation method depends on intraoperative inspection of the fracture pattern, degree of bone loss or comminution, and soft tissue coverage.
6. Absolute stability permits direct/primary bone healing and can be achieved using lag screw and plate fixation or compression plating for simple fracture patterns with adequate cortical contact as in this case. Lag screws were unable to be used due to the transverse fracture indicating compression plating to achieve adequate stability.
7. Complex fracture patterns with bone loss or comminution require a construct that affords relative stability for

indirect/secondary bone healing such as bridge plating. Indirect reduction techniques can be employed with percutaneous plating options to preserve the soft tissue envelope and periosteal blood supply at the fracture site.

6 Images During Treatment

See Figs. 2, 3, and 4.

Fig. 2 Intraoperative anteroposterior (a) and lateral (b) fluoroscopic images of the right distal tibia showing restored anatomic alignment, adequate cortices engaged with the screws through the plate, and no gapping at the fracture site with the exception of a very small anterolateral fragment removed with the open fracture debridement

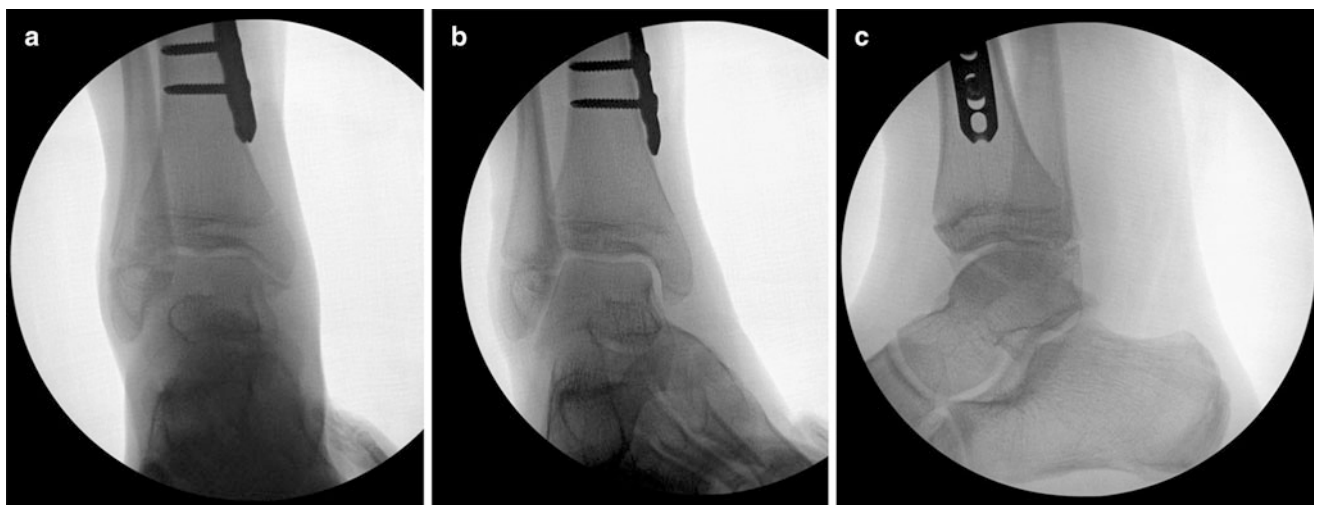
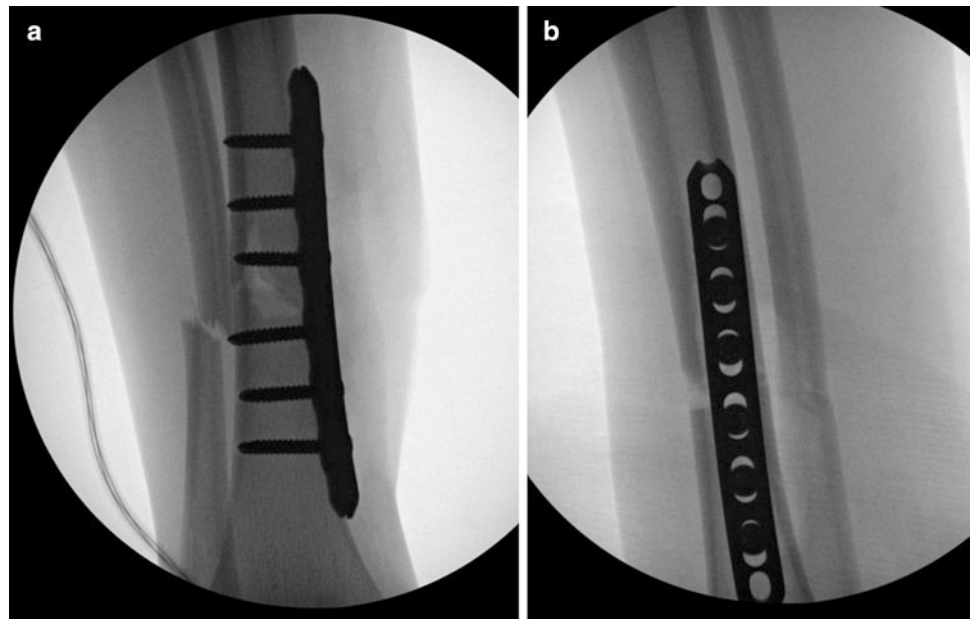


Fig. 3 Intraoperative anteroposterior (a), oblique (b), and lateral (c) fluoroscopic images of the right ankle showing adequate alignment of the ankle mortise and a non-displaced medial malleolus fracture of the anterior colliculus that did not require operative fixation

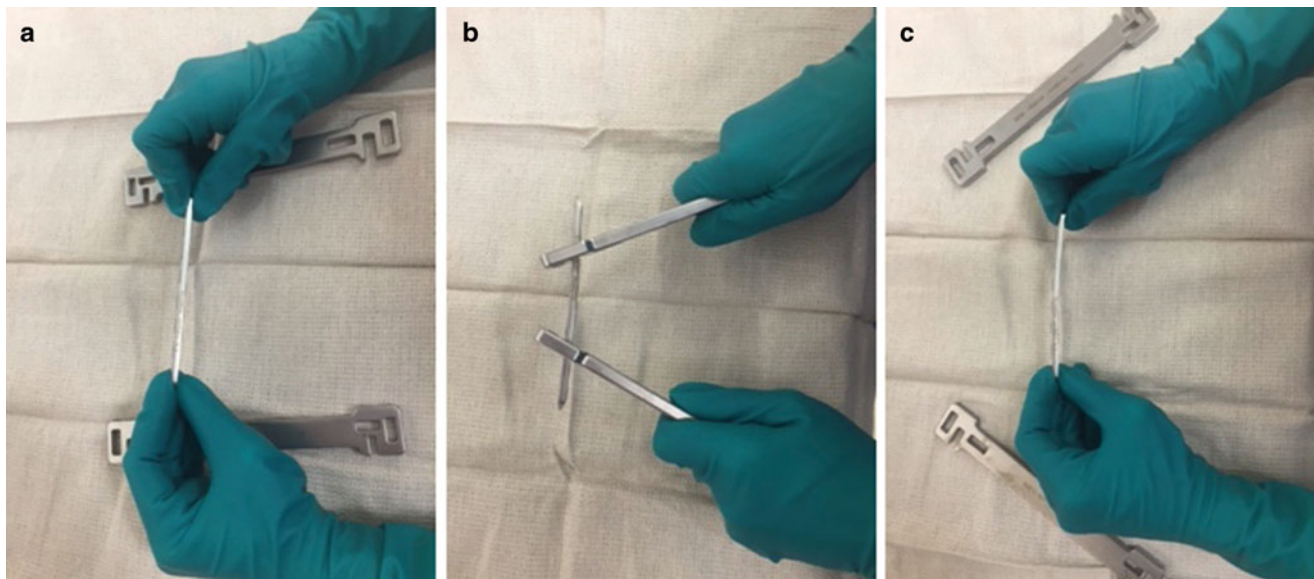


Fig. 4 Dynamic compression plate (a) selected to stabilize the transverse fracture pattern. Technique for precontouring the implant (b) with a subtle convex bend at the fracture level (c) to ensure the opposite side of the fracture remains compressed during the fixation

7 Technical Pearls

1. The operating room is arranged with a radiolucent table and fluoroscopy positioned opposite the surgeons. Consider setting up a separate sterile instrumentation table to use after the debridement in the scenario of open fractures.
2. The open wound should be extended sufficiently to expose and deliver the proximal and distal fractured bone ends for debridement without creating unnecessary additional periosteal stripping.
3. Reduction of the tibia is achieved directly and maintained by clamping the plate to the proximal and distal fractured ends.
4. The plate type and length are selected to allow six cortices of fixation above and below the fracture.
5. If lag screw fixation is unable to be achieved, compression plate technique will achieve absolute stability when direct bone healing is desired.
6. Prebend the plate with a small convex angle at the fracture site (Fig. 4). The plate will straighten as it compresses against the bone forcing the opposite cortex to compress.
7. A neutral bicortical 3.5 mm screw secures the plate to either the proximal or distal segment. Compression is achieved by drilling the next screw eccentrically through one of the plate holes in the opposite bone segment. This maneuver can be performed twice to achieve maximal compression.
8. Alternatively, an external screw-driven compression device can be used to achieve the same compressive effect.
9. Separate fluoroscopic images of the knee and ankle are obtained to exclude associated injury, paying particular attention in skeletally immature patients for physeal widening that may signify a Salter Harris 1 injury of the proximal or distal tibia.
10. The decision to immobilize depends on the axial, angular, and rotational stability of fixation and presence of associated injuries.
11. Progressive weight bearing is initiated when radiographs suggest three of four cortices with bridging bone (average 6–12 weeks), and ankle range of motion and Thera-Band strengthening exercises are performed independently or under the guidance of a physical therapist.
12. Patients are released to unrestricted activity in 3–6 months when strength and mobility return, assuming absence of pain with activities and routine healing on radiographs.

8 Outcome Clinical Photos and Radiographs

See Figs. 5 and 6.

Fig. 5 Anteroposterior (a) and lateral (b) radiographs of the right distal tibia 3 months after surgery show bridging bone of at least three cortices and a healed fibula. The patient returned to unrestricted activity 6 months postoperatively

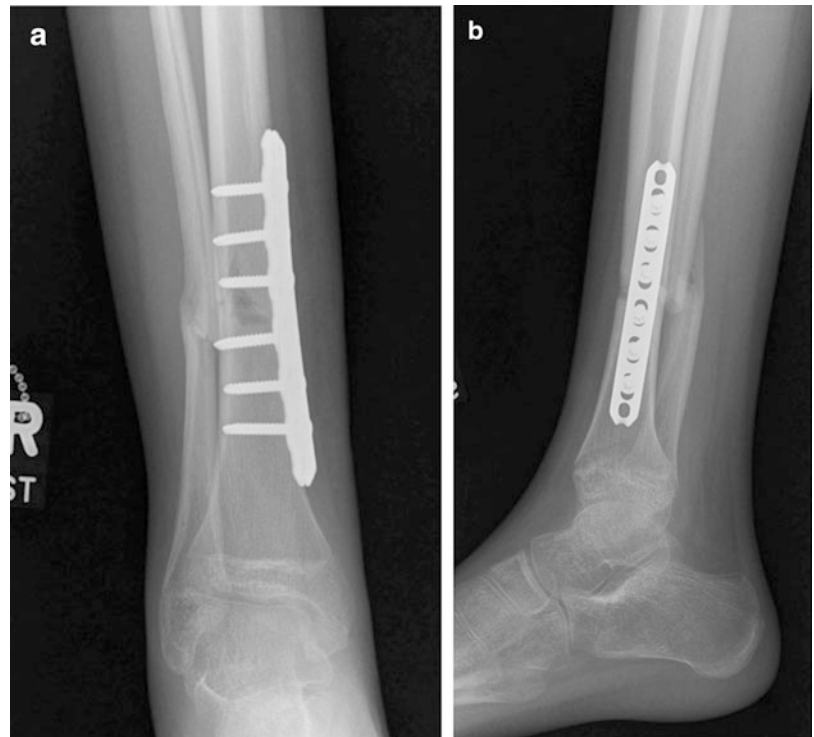
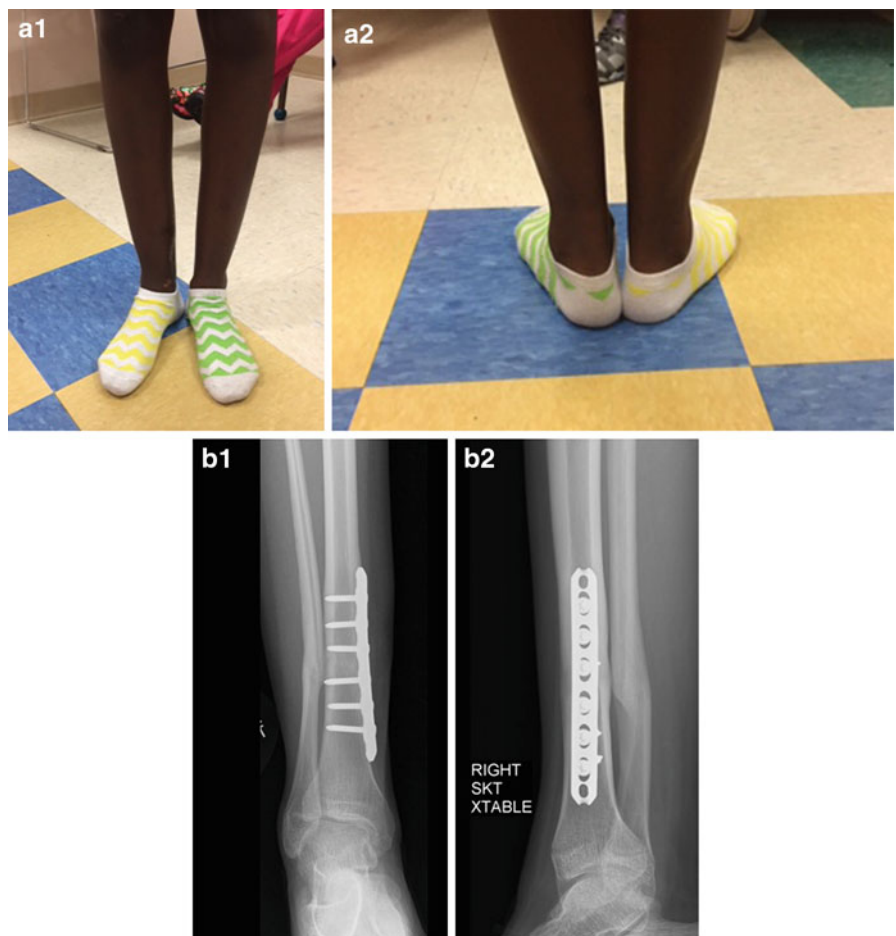


Fig. 6 Clinical photos (a) and radiographic images (b) 1 year after surgery showing symmetric lower extremity alignment and remodeling of the tibia. The patient participates in dance without pain or functional difficulties



9 Avoiding and Managing Problems

1. A careful preoperative clinical and radiographic examination can avoid missing associated ipsilateral injuries of the extremity, particularly of the ankle.
2. Be prepared with a variety of fixation options in the operating room including internal and external fixation devices.
3. Choose the appropriate plate construct to achieve absolute or relative stability based on the fracture pattern and desired type of bone healing to prevent nonunion and fixation failure.
4. Use indirect reduction techniques and percutaneous plating when possible to preserve the biological healing process.
5. Follow patients at regular intervals to evaluate for loss of alignment, fixation failure, and delay/nonunion that may warrant secondary procedures.

10 Cross-References

- [Isolated Medial Malleolus Fracture](#)
- [Submuscular Plating of Tibial Fractures](#)

- [Tibial Shaft Fracture: Flexible Nails](#)
- [Tibial Shaft Fracture Treated with a Circular External Fixator](#)

References and Suggested Reading

- Aslani H, Tabrizi A, Sadighi A et al (2013) Treatment of open pediatric tibial fractures by external fixation versus flexible intramedullary nailing: a comparative study. *Arch Trauma Res* 2:108–112
- Head J, Lewis T, Puffinbarger W et al (2014) Plating of open pediatric tibia fractures. *J Okla State Med Assoc* 107(7):382–383
- Masquijo J (2014) Percutaneous plating of distal tibial fractures in children and adolescents. *JPO B* 23(3):207–2011
- Ozkul E, Gem M, Arslan H et al (2016) Minimally invasive plate osteosynthesis in open pediatric tibia fractures. *JPO* 36(4):416–422
- Pandya N, Edmonds E (2012) Immediate intramedullary flexible nailing of open pediatric tibia shaft fractures. *JPO* 43(8):770–776
- Setter K, Palomino K (2006) Pediatric tibia fractures: current concepts. *Curr Opin Pediatr* 18(1):30–35
- Tencer A (2006) Biomechanics of fixation and fractures. In: Bucholz R, Heckman J, Court-Brown C (eds) *Rockwood and Green's fractures in adults*, 6th edn. Lippincott Williams and Wilkins, Philadelphia, pp 3–41. Print
- Yusof N, Oh S, Oh J et al (2009) Percutaneous plating in pediatric tibia fractures. *Injury* 40:1286–1291

Submuscular Plating of Tibial Fractures

Javier Masquijo

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Abstract

A 14-year-old male sustained a displaced closed left distal tibia fracture while playing rugby. Closed reduction was attempted and a long leg cast was applied. An acceptable reduction was achieved intraoperatively, but loss of alignment was noted at 1-week follow-up. Treatment options included cast wedging, elastic intramedullary nailing (ESIN), external fixation or open reduction, and plating. Definitive management consisted of submuscular plate fixation with manual closed reduction to preserve the periosteal blood supply. This technique does not interfere with the fracture site and thus provides excellent angular stability with improved healing potential. The fracture healed uneventfully in 10 weeks. Percutaneous plating is one of several options in the management of tibia fractures in skeletally immature patients. Because of its biologic advantages and stable fixation that allows early

mobilization, percutaneous plating is a reasonable treatment option for older children and adolescents with complex-unstable fractures of the tibia.

1 Brief Clinical History

A 14-year-old male sustained a closed left distal tibia fracture that occurred while playing rugby. Physical examination revealed swelling and tenderness over the distal tibia. The affected leg was shortened and externally rotated. Neurovascular examination was normal. Radiographs revealed a displaced long oblique distal tibial fracture and a displaced proximal fibula fracture. Closed reduction and cast application under general anesthesia was initially performed. Acceptable reduction was achieved intraoperatively, but loss of alignment with valgus, procurvatum, and external rotation

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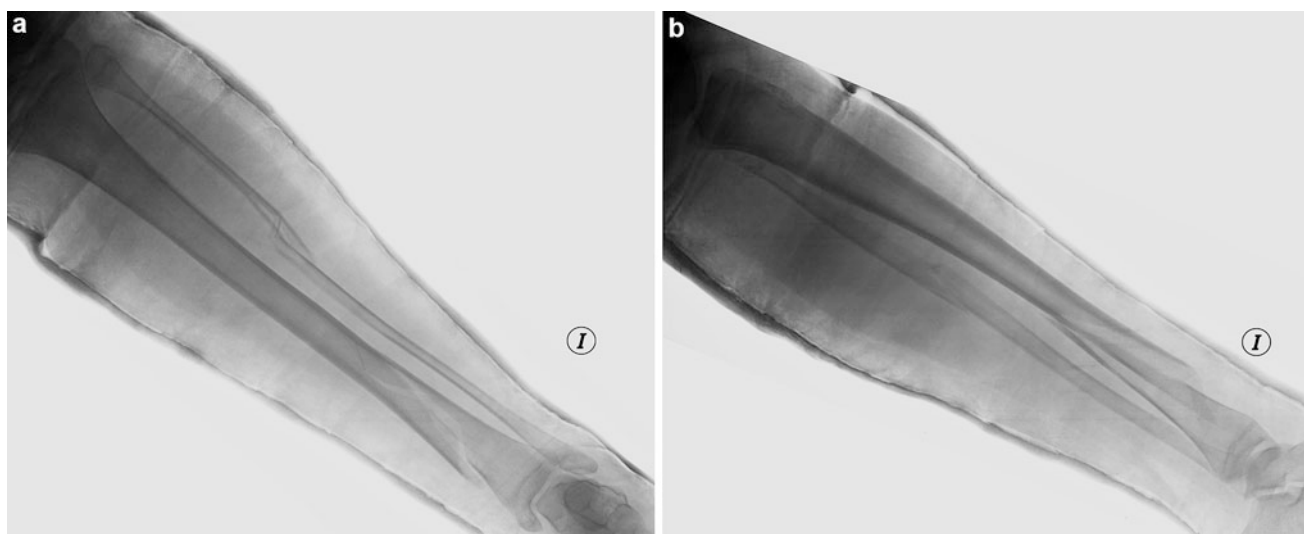


Fig. 1 Anteroposterior (a) and lateral (b) views demonstrate the displaced long oblique fracture of the distal tibia at 1-week reduction. The physes are intact

was noted at 1-week follow-up (Fig. 1). Due to the fracture instability, it was decided to proceed with a submuscular plate to provide a stable fixation while preserving the periosteal blood supply.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Unstable distal tibial fracture
2. Open physis
3. Choice of fracture fixation

4 Treatment Strategy

The majority of tibial shaft fractures in skeletally immature patients heal well with nonoperative treatment, though loss of reduction may occur in unstable fractures. Mild to moderate angular deformity can be safely corrected by wedging the cast. Wedging was unlikely to correct the bi-planar deformity in this case.

There were multiple treatment options. Elastic stable intramedullary nailing (ESIN) has been designed specifically

for the treatment of diaphyseal fractures. However, in proximal and distal tibia fractures, this method is technically demanding and not free of complications. A locked intramedullary nail was not ideal due the open proximal tibial physis and the risk of physeal injury. External fixation is particularly useful in open tibia fractures and patients with multiple injuries but is associated with frequent complications such as superficial pin tract infections, delayed union, and refracture. Open reduction and plating would require a large exposure through the zone of injury, which can increase the risk of infection or delayed union or nonunion. Therefore, submuscular plating was felt to be the best option for this injury. This technique offers stable fixation with limited disruption to fracture healing.

5 Basic Principles

1. Submuscular plating is particularly useful in achieving stable fixation of complex-unstable fractures of the tibia in older children and adolescents.
2. Using indirect reduction techniques preserves the soft-tissue envelope, periosteum, and maintains arterial vascularity thus minimizing the surgical trauma to the zone of injury.
3. Furthermore, this more biologically friendly technique can result in accelerated fracture healing, improved patient comfort, early return to limb function, and a lower incidence of postoperative complications.

6 Images During Treatment

See Figs. 2 and 3.

7 Technical Pearls

1. The patient is positioned supine on a radiolucent table.
2. The distal fibula fracture, if present, is addressed first. This provides lateral stability and allows restoration of the limb length. The fibula fracture in this case was proximal and did not require fixation.
3. The main fracture fragments of the distal tibia were aligned using manual indirect reduction. Fixation may be achieved with a provisional percutaneously applied clamp or 4.5-mm lag screws.



Fig. 2 Minimally invasive plate insertion through a small incision above the medial malleolus



Fig. 3 Proximal and distal incisions are used to place the plate in proper position

4. Special attention is paid to avoid any malrotation.
5. The length of the plate should be such that at least two bicortical screws may be inserted proximal and distal to the fracture. Anatomically shaped plates are helpful but not necessary for this technique. Straight plates can be contoured to fit the bony surface.
6. A 3 cm incision is made proximal to the distal tibial physis, and a subcutaneous tunnel is created (Fig. 2). The plate is introduced subcutaneously through the tunnel. An additional incision is made at the proximal end to manipulate the plate (Fig. 3).
7. The position of the plate is adjusted on both the AP and lateral views. At this point, the plate is provisionally secured with K-wires through proximal and distal holes.
8. Limb alignment and plate position are assessed with an image intensifier in anteroposterior/lateral views. Two or three bicortical screws are then inserted at either end of the plate (Fig. 4).
9. The stability of the fixation is verified with full passive range of motion under fluoroscopy.
10. The patient is immobilized in a below-knee non-weight-bearing cast for 3 weeks. At the third week after surgery, 25% weight-bearing gait is allowed. Full-weight-bearing gait is permitted once complete healing is achieved.
11. Consider removing the plate in the first year after the fracture is healed as the subcutaneous placement of the plate is likely to be symptomatic (Fig. 5).

8 Outcome Clinical Photos and Radiographs

See Figs. 4 and 5.

9 Avoiding and Managing Problems

1. Intraoperatively, always inspect the legs visually as an additional check for alignment errors.
2. A careful incision and dissection over the distal tibia is recommended to avoid saphenous nerve injury.
3. Three studies (Heyworth et al. 2013; May et al. 2013; Kelly et al. 2013) reported distal femoral valgus after submuscular plating in the femur in skeletally immature patients. Although distal tibia grows slower, this could be a potential complication and requires close monitoring.

Fig. 4 Anteroposterior (a) and lateral (b) radiographs at 10 weeks show excellent alignment and consolidation of the tibia

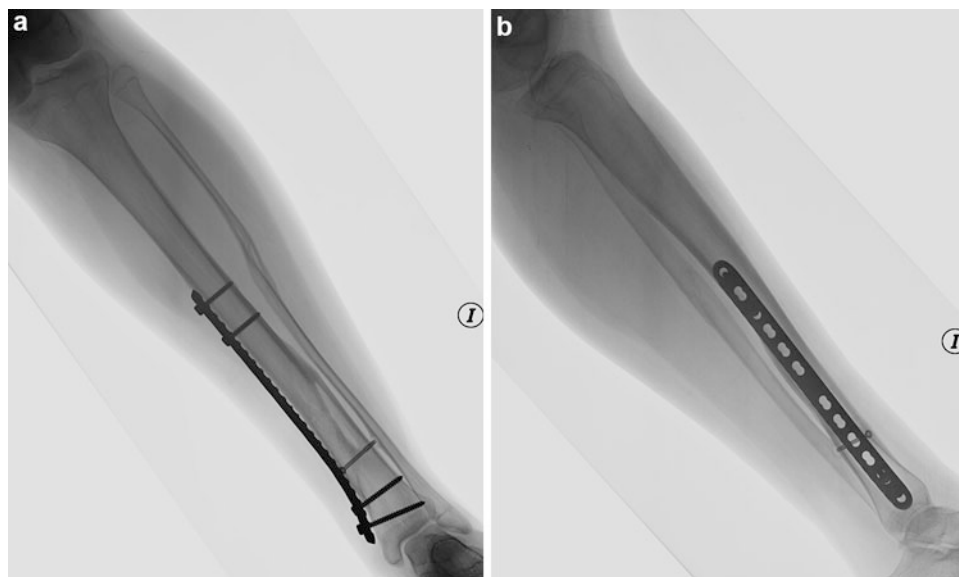
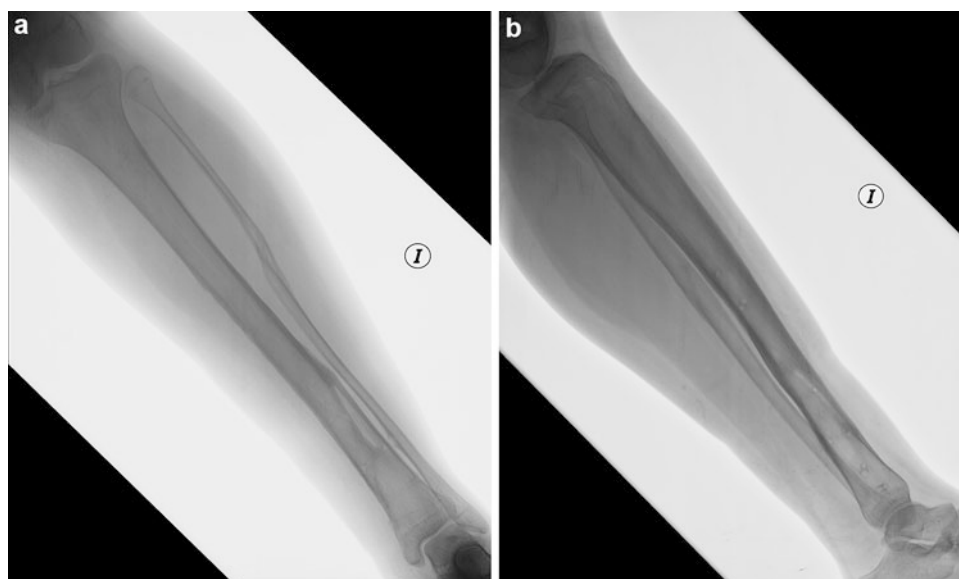


Fig. 5 Anteroposterior (a) and lateral (b) radiographs at 1-year follow-up show a healed distal tibia after hardware removal



10 Cross-References

- [Tibial Shaft Fracture: Flexible Nails](#)
- [Tibial Shaft Fracture: Plating](#)

References and Suggested Reading

- Gordon JE, Gregush RV, Schoenecker PL, Dobbs MB, Luhmann SJ (2007) Complications after titanium elastic nailing of pediatric tibial fractures. *J Pediatr Orthop* 27:442–446
- Heyworth BE, Hedequist DJ, Nasreddine AY, Stamoulis C, Hresko MT, Yen YM (2013) Distal femoral valgus deformity following plate fixation of pediatric femoral shaft fractures. *J Bone Joint Surg Am* 95(6):526–533
- Kelly B, Heyworth B, Yen YM, Hedequist D (2013) Adverse sequelae due to plate retention following submuscular plating for pediatric femur fractures. *J Orthop Trauma* 27(12):726–729
- Masquijo JJ (2014) Percutaneous plating of distal tibial fractures in children and adolescents. *J Pediatr Orthop B* 23(3):207–211
- May C, Yen YM, Nasreddine AY, Hedequist D, Hresko MT, Heyworth BE (2013) Complications of plate fixation of femoral shaft fractures in children and adolescents. *J Child Orthop* 7(3): 235–243
- Srivastava AK, Mehlman CT, Wall EJ, Do TT (2008) Elastic stable intramedullary nailing of tibial shaft fractures in children. *J Pediatr Orthop* 28:152–158
- Toms AD, McMurtie A, Maffulli N (2004) Percutaneous plating of the distal tibia. *J Foot Ankle Surg* 43:199–203
- Yusof NM, Oh CW, Oh JK, Kim JW, Min WK, Park IH, Kim HJ (2009) Percutaneous plating in paediatric tibial fractures. *Injury* 40:1286–1291



Tibial Shaft Fracture Treated with a Rigid Nail

Brian E. Kaufman

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Abstract

Tibial shaft fractures are common in children and adolescents, accounting for nearly 15% of long-bone fractures in this population. In adults, the operative treatment of displaced tibial shaft fractures continues to become more ubiquitous with closed, cast treatment occurring less frequently. Conversely, the vast majority of tibial shaft fractures in children and adolescents can be successfully managed with closed reduction and cast immobilization. Intramedullary nail treatment in the adolescent is indicated at or near skeletal maturity as injury to the proximal tibial physis or anterior tibial tubercle from nail insertion can risk growth disturbance, limb-length discrepancy, and recurvatum of the proximal tibia. In adolescents, tibial shaft fractures are high-energy injuries that may frequently be complicated by significant soft tissue injury. Careful

examination of the neurovascular status of the limb is critical. The surgeon must remain aware of the nearly 10% rate of compartment syndrome in open tibial shaft fractures. Initial assessment with plain radiographs is sufficient keeping in mind that spiral distal tibial shaft fractures may extend to the tibiotalar joint with an associated posterior malleolar fragment in up to 39% of cases. Successful intramedullary nail treatment is predicated on careful attention to the nail start point on both the AP and lateral planes to prevent iatrogenic angular deformity. Intramedullary nails are load sharing devices, and immediate weight bearing is possible with the caveat that average time to union can approach 18 weeks.

1 Brief Clinical History

The patient is a 15-year-old male who presented with an open injury to his left lower leg after jumping off a 14 foot roof. He denied pain elsewhere and was neurovascularly intact throughout both lower extremities. The compartments of his left leg were soft, and he denied pain with passive motion of

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the toes. There was a 4×3 cm transverse wound over the distal anterior leg with exposed tibia visible at its base. Radiographs revealed transverse fractures of the tibia and fibula in the distal one third of the diaphysis without intra-articular extension (Fig. 1a–e). The wound was lightly irrigated in the emergency department with a saline and dressed with moist sterile gauze. The patient was then placed into a well-padded long-leg splint (Fig. 2a–b). A tetanus booster and weight-based Ancef dosing were provided immediately upon presentation.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2

3 Preoperative Problem List

1. Open, transverse, distal diaphyseal fractures of the tibia and fibula without intra-articular extension
2. 4×3 cm laceration with potential for soft tissue devitalization and significant periosteal stripping

4 Treatment Strategy

In order to minimize the risk of infection, this patient was provided with antibiotics immediately upon evaluation in the emergency department. In the absence of strong evidence demonstrating reduced rates of complications or infections

with immediate operative intervention, definitive treatment was delayed until the following morning, and the patient was temporized with limited irrigation and splinting of the injured limb.

Intraoperatively, the transverse wound was extended proximally and distally in a “Z” fashion to minimize the risk of wound necrosis. The soft tissues and fracture ends were debrided of gross contamination, and the wound was thoroughly irrigated with 6 L of normal saline using low-pressure, gravity irrigation with cystoscopy tubing. High-pressure pulsatile irrigation has not been demonstrated to lower rates of infection and may further traumatize the soft tissues. Additives to the irrigant solution such as antibiotics, povidone iodine, or soap have not demonstrated lower rates of infection or wound complications. Therefore, low-pressure irrigation with simple saline is preferred.

Owing to the shorter time to union compared to cast treatment, internal stabilization of the fracture was selected. Fixation options included intramedullary nailing, plating, or external fixation. Plating, either submuscular or open, was avoided to minimize further soft tissue stripping and to provide a load-sharing construct that would allow early weight bearing. External fixation, either with a ring fixator or unilateral fixator, would have been possible. As the fracture was not comminuted and the soft tissue injury was amenable to primary closure, rigid nail fixation was preferred to avoid the potential for pin tract infection and the need for later removal of the fixator.

A patellar-tendon splitting approach was then utilized to expose the proximal tibial metaphysis for insertion of the tibial nail guide wire. A medial para-patellar approach may also be utilized. The patellar-splitting approach has not



Fig. 1 (a–e) Injury presentation AP and lateral radiographs demonstrating transverse fractures of the distal third of the tibial and fibular diaphyses without intra-articular extension

Fig. 2 (a–b) Postreduction AP and lateral radiographs in a long-leg splint



shown increased pain or complications and, in the author's opinion, minimizes the potential for valgus angulation of the proximal fragment. Acceptable placement of the guide wire on biplanar fluoroscopy was obtained. The traumatic wound was used to assist with reduction and reamed, intramedullary nailing proceeded in the standard fashion. The traumatic wound was closed with low-tension interrupted sutures, and the patient was placed into a short-leg splint postoperatively with the plan for early weight bearing at 2 weeks after healing of the soft tissues.

5 Basic Principles

1. Administration of antibiotics greater than 3 h after injury has been demonstrated to significantly increase the risk of infection in open fractures (Patzakis and Wilkins 1989).
2. For non-contaminated open fractures, first-generation cephalosporins provided adequate antibiotic coverage. Some authors will advocate for the use of gram-negative coverage in severe wounds. Penicillin G is reserved for grossly contaminated wounds to prevent clostridial myonecrosis (Melvin et al. 2010a).
3. In accordance with Gustilo and Anderson's initial recommendations, the classification of open fractures occurs in the operating room (Gustilo and Anderson 1976). The skin laceration may underestimate the degree of soft tissue and periosteal stripping at the level of the fracture. This point is particularly relevant in tibial shaft fractures in which there is little soft tissue coverage anteromedially. Despite a wound measuring only 4×3 cm, this patient's wound was graded as a Gustilo type IIIA open fracture upon evaluation in the OR.
4. Irrigation and debridement of the open fracture should occur within 24 h of admission to the hospital. Srour et al. prospectively demonstrated no difference in infection rates between open fractures of all grades treated less than 6 h, 7–12 h, 13–18 h, and 19–24 h after presentation (Srour et al. 2014). In the absence of gross contamination and neurovascular compromise, the author believes it safe to treat an open fracture within 24 h of admission. No irrigation or debridement is attempted in the emergency room. The open wound is typically covered with a moist dressing and the limb is splinted.
5. The FLOW investigators have demonstrated that very low-pressure saline irrigation is the safest and most cost-effective treatment for open fractures (Bhandari et al. 2015). High-pressure, pulsatile irrigation does not provide a benefit in terms of rates of infection or need for reoperation. The addition of antibiotics, povidone iodine, or soap to the irrigant solution has not shown any benefit when compared to simple saline (Bhandari et al. 2015).
6. Whenever possible, primary repair of the soft tissue should be attempted in a tension-free manner. If necessary, rotational or free-flap coverage should occur within 7–10 days so as to minimize the risk of infection (Melvin et al. 2010b).
7. Successful intramedullary nailing is predicated on accurate guide wire start-point placement. Technical pearls to achieve the correct start-point are described below. Furthermore, fracture gapping should be minimized to allow close cortical opposition and to promote healing (Boulton and O'Toole 2015).
8. Reamed nailing is thought to improve the biologic environment for fracture healing despite the theoretical risk to the cortical blood supply. The SPRINT trial demonstrated that one possible benefit to the use of reamed nails in

closed tibia fractures may be avoiding the need for future bone grafting or implant exchanges as compared to unreamed nails (SPRINT Investigators 2008).

6 Images During Treatment

See Figs 3 and 4

7 Technical Pearls

1. Knee flexion over a triangle bump can facilitate both fracture reduction and the ability to easily pass the guide wire and intramedullary nail.
2. Adequate C-arm radiographs are necessary to avoid iatrogenic malalignment with nail placement. On a true AP, the lateral border of the lateral condyle of the tibia bisects the head of the fibula. The femoral condyles overlap on a true lateral of the knee.
3. In the coronal plane, the ideal start point is just medial to the lateral tibial spine. Sagittally, the nail should enter the proximal tibia just anterior to the articular surface taking care to avoid damage to the mensci (start point too proximal) or tibial tubercle (start point too distal).
4. In both the coronal and sagittal planes, the guide wire should be directed down the center of the medullary canal. In the sagittal plane, the straight guide wire will inevitably start anteriorly and be directed posteriorly. As long as 8–10 cm of the wire is inserted into the proximal tibia, opening reaming will not be affected. Remember that the final implant has a Herzog bend proximally which will accommodate for the proximal bow of the tibia and will direct the final implant down the center of the medullary canal.

5. Center-center positioning of the wire in the distal fragment allows anatomic restoration of the tibial mechanical axis. Iatrogenic malalignment in proximal and distal fractures can be avoided with the use of blocking screws placed in the concavity of the potential deformity (i.e., laterally to avoid valgus and posteriorly to avoid procurvatum for proximal fractures) (Tejwani et al. 2014; Boulton and O'Toole 2015).
6. For proximal fractures, the use of a suprapatellar starting point may obviate iatrogenic procurvatum deformity after nail insertion. The suprapatellar start point allows the nail to be inserted in a semi-extended position, which may facilitate fracture reduction. An intra-articular sleeve must be utilized to prevent damage to the articular cartilage of the trochlear groove. Recent literature has demonstrated little difference in postoperative outcomes with respect to knee function and rates of iatrogenic chondromalacia with this method when compared to standard, infrapatellar nail insertion (Chan et al. 2016; Sanders et al. 2014).

8 Outcome Clinical Photos and Radiographs

See Fig. 5

9 Avoiding and Managing Problems

1. The infection rate of open tibia fractures can be as high as 16%. Best practices to minimize the risk of infection include early antibiotic administration and soft tissue coverage.

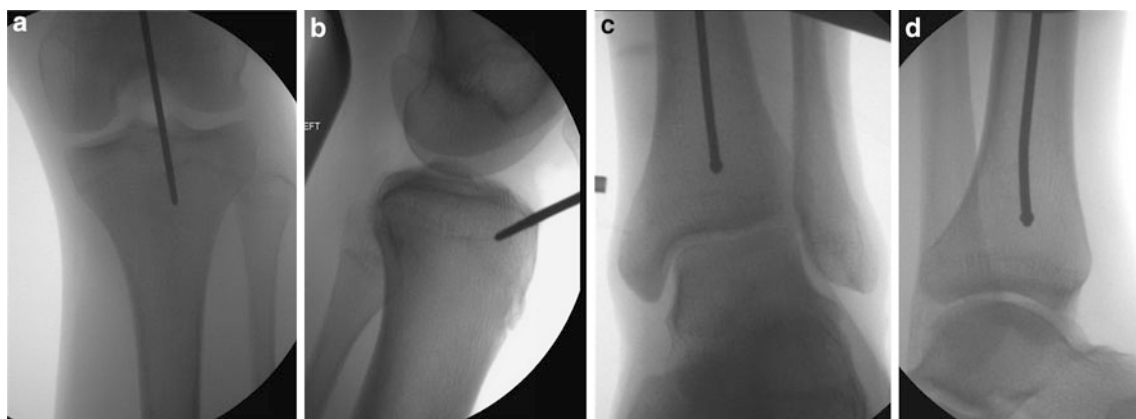


Fig. 3 (a–d) Intraoperative fluoroscopy demonstrating guide wire start point (a, > b). In a true AP image, the lateral border of the lateral condyle of the tibia should bisect the head of the fibula. The guidewire should enter the proximal tibia just medial to the lateral tibial spine. This wire was adjusted to take a more anatomic path. On the lateral, the start point

is just anterior to the articular surface and proximal to the tibial tubercle. It should be aimed parallel to the anterior cortex and in line with the shaft of the tibia. (c) and (d) demonstrate a center-center position of the guidewire in the distal fragment, ensuring concentric reaming and near anatomic alignment of the fracture after passage of the nail



Fig. 4 (a–b) Immediate postoperative radiographs demonstrating near anatomic alignment of the fracture with minimal diastasis at the fracture site after passage of a rigid, intramedullary nail



Fig. 5 (a–b) Radiographs 7 months postoperatively demonstrating healed fractures of the tibia and fibula in near anatomic alignment. The patient had no complaints and was released to unrestricted activity including contact sports

2. The clinician should have a high clinical suspicion for compartment syndrome and recognize that the presence of an open fracture does not indicate an adequate fascial release has been performed. The incidence of compartment syndrome is higher in open fractures than in closed fractures. Compartment syndrome is treated with emergent four-compartment fasciotomy.
3. Intraoperatively recognized malalignment after nail placement can be corrected with the use of blocking screws in the concavity of the caused deformity.
4. Anterior knee pain can occur postoperatively in up to 50% of patients. Evaluate the lateral radiograph intraoperatively to ensure the nail is not left proud.
5. Malunion can be avoided with careful surgical technique and understanding of the accepted parameters of reduction: $<5^\circ$ of varus/valgus, $<10^\circ$ of procurvatum/recurvatum, 50% cortical opposition, <1 cm of shortening, and $<10^\circ$ of rotational malalignment.
6. Nonunion rates can approach 10% in closed fractures and 27% in open fractures. Noninfected nonunions can be effectively treated with reamed exchange nailing.

10 Cross-References

- [Submuscular Plating of Tibial Fractures](#)
- [Tibial shaft Fracture: Flexible nails](#)
- [Tibial shaft Fracture: Plating](#)
- [Tibial Shaft Fracture with Bone Loss](#)
- [Tibial Shaft Fracture with Soft Tissue Loss](#)

References and Suggested Readings

- Bhandari M, Jeray KJ, Petrisor BA et al (2015) A trial of wound irrigation in the initial management of open fracture wounds. *N Engl J Med* 373(27):2629–2641
- Boulton C, O'Toole RV (2015) Tibia and fibula shaft fractures. In: Court-Brown CM (ed) *Rockwood and Green's fractures in adults*, 8th edn. Lippincott, Williams, & Wilkins, Philadelphia, pp 2415–2472
- Chan DS, Serrano-Riera R, Griffing R et al (2016) Suprapatellar versus infrapatellar tibial nail insertion: a prospective randomized control pilot study. *J Orthop Trauma* 30(3):130–134
- Gustilo RB, Anderson JT (1976) Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. *J Bone Joint Surg Am* 58:453–458
- Mashru RP, Herman MJ, Pizzutillo PD (2005) Tibial shaft fractures in children and adolescents. *J Am Acad Orthop Surg* 13: 345–352
- Melvin JS et al (2010a) Open tibial shaft fractures: II. Definitive management and limb salvage. *J Am Acad Orthop Surg* 18:108–117

- Melvin JS et al (2010b) Open tibial shaft fractures: I. Evaluation and initial wound management. *J Am Acad Orthop Surg* 18:10–19
- Patzakis MJ, Wilkins J (1989) Factors influencing infection rate in open fracture wounds. *Clin Orthop Relat Res* 243:36–40
- Sanders RW, Dipasquale TG, Jordan CJ et al (2014) Semiextended intramedullary nailing of the tibia using a suprapatellar approach: radiographic results and clinical outcomes at a minimum of 12 months follow-up. *J Orthop Trauma* 28(8 suppl): S29–S39
- SPRINT Investigators (2008) Study to prospectively evaluate reamed intramedullary nails in patients with tibial fractures. *J Bone Joint Surg Am* 90(12):2567–2578.
- Srour M, Inaba K, Okoye O et al (2014) Prospective evaluation of treatment of open fractures: effect of time to irrigation and debridement. *JAMA Surg* 150(4):332–336
- Tejwani N, Polonet D, Wolinsky PR (2014) Controversies in the intramedullary nailing of proximal and distal tibia fractures. *J Am Acad Orthop Surg* 22:665–673

Tibial Shaft Fracture Treated with a Circular External Fixator

Kevin M. Neal and Eric D. Shirley

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Abstract

Tibial shaft fractures in children and adolescents require special consideration when determining the most appropriate treatment due to the presence of open, growing physes. While antegrade, reamed, locked intramedullary nailing remains the most common treatment for similar adult injuries, it is not commonly performed in growing children due to the requirement of a relatively large entry site through the proximal tibial physis, risking physeal arrest. Goals of surgical treatment for tibial shaft fractures in children and adolescents include restoration of normal limb alignment and length, without risking further damage to the growing physis. Options to treat tibial shaft fractures in these age

groups typically include closed manipulation and casting, flexible intramedullary nails, and external fixation. This chapter discusses the relative benefits of external fixation, the author's preferred fixation technique, and typical post-operative protocols.

A 12-year-old boy presented after falling on a trampoline and sustaining an injury with obvious pain and deformity of the right lower leg. Radiographs in the emergency department revealed a displaced fracture of the right tibial shaft, with an associated fracture of the proximal fibular shaft. Attempted closed manipulation was performed under sedation, but the fracture remained displaced, shortened, and slightly angulated. After a discussion of options with the family, the patient was given a general anesthetic; a circular external fixator was applied to the proximal and distal tibial shaft, spanning the tibial fracture site; and the fracture was reduced. No other supplemental immobilization was required. The patient was allowed to bear weight as tolerated, perform range of motion exercises of the knee and ankle as tolerated, and perform daily, routine pin site care. The patient healed the tibial fracture well, and the

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external fixator was removed under a second general anesthetic about 10 weeks later.

1 Brief Clinical History

A 12-year-old boy injured his right lower leg while jumping on a trampoline. He had immediate pain, swelling, deformity, and the inability to walk on the right side. Evaluation in the emergency department revealed displaced right tibial and fibular shaft fractures, with intact motor and sensory function in the right leg, as well as a normal dorsalis pedis pulse and normal capillary refill in the toes. Attempted closed manipulation and casting was performed, but the fracture remained somewhat displaced, shortened, and angulated. (Fig. 1).

2 Preoperative Clinical Photos and Radiographs

See Fig. 1, following Closed Manipulation

3 Preoperative Problem List

1. Tibial shaft fracture with proximal fibula fracture
2. Open physes

4 Treatment Strategy

Treatment options include closed manipulation and casting, percutaneous fixation using flexible intramedullary nails, reamed, locked intramedullary nailing, submuscular

plating, and external fixation. Though closed manipulation and casting is an option, tibial shaft fractures in this age group have potential for late angulation and displacement, which could lead to malunion. Additionally, treatment of these injuries by closed methods typically requires prolonged casting, and a period of limited weight bearing. Flexible intramedullary nailing is a viable treatment option, though may require additional external immobilization to prevent malunion. Reamed, locked intramedullary nailing would require a nail entry point through the growing proximal tibial physis and risk physeal arrest. Submuscular plating is an option, though rigid internal fixation may increase the rate of nonunion in tibial shaft fractures. External fixation provides adequate stability for healing, allows immediate weight bearing and full range of motion of the knee and ankle, and does not risk damaging the growing physes.

5 Basic Principles

1. Proximally, a two-thirds ring is used to allow unrestricted knee flexion. Variably sized rancho cubes are attached to the ring, through which half pins will be placed.
2. Two, bicortical external fixation half pins are inserted proximal to the fracture site through the rancho cubes. For larger children and adolescents, 6.0 mm, hydroxyapatite-coated pins are preferred.
3. A full ring is attached distal to the fracture site in the same fashion, using two bicortical half pins.
4. Six spatial frame struts are placed between the rings. Non-locked struts that allow manipulation of the fracture are our preferred method. The struts are tightened to the rings.

Fig. 1 AP (a) and lateral (b) views of the right leg, demonstrating a displaced, shortened, angulated tibial shaft fracture with an associated proximal fibular fracture



5. A manipulative reduction of the fracture is performed, and the struts are locked into place. Anatomic reduction is not required, as the spatial frame can be used to improve the reduction postoperatively.
6. AP and lateral radiographs of the tibia are taken, including the entirety of both rings to allow for postoperative planning. (Fig. 2)
7. Spatial frame systems have proprietary software programs that allow programming of the current deformity, frame size, frame position, and the desired rate of correction. They can generate a daily program of strut adjustments to correct any residual deformity.
8. Weight bearing, knee range of motion, and ankle range of motion are allowed as tolerated postoperatively.
9. Patients are taught to care for their pin sites daily and can typically shower immediately. Our preferred method is cleaning with soap and water during daily showers.
10. Patients are followed at the end of any programmed correction with radiographs to determine adequacy of the fracture position. Any residual deformity can be reprogrammed using spatial frame software. (Fig. 2)
11. Physical therapy can be initiated for weight bearing, knee and ankle range of motion exercises, and quadriceps and calf strengthening, as soon as patients are comfortable.
12. Gradual dynamization of the frame should be performed during the course of treatment to transfer more load to the healing bone. The connection between one of the half pins and the ring can be loosened proximally and distally once early healing has been visualized on the radiographs. The patient should be able to comfortably fully weight bear in the frame both before and after the dynamization.
13. Once adequate healing has been confirmed on postoperative radiographs; an outpatient procedure under anesthesia can be scheduled to remove the frame and hydroxyapatite-coated pins. (Fig. 3)
14. Weight bearing, range of motion, and quadriceps and calf strengthening can still be performed after pin removal. About 6 weeks is allowed for the pin sites to fill with bony matrix prior to releasing patients for sports and vigorous physical activity.

6 Images During Treatment

See Fig. 2

7 Technical Pearls

1. Provisional long, skinny wires may be placed transversely proximal and distal to the fracture site and used to provide provisional stabilization of the rings during half pin insertion. They can be removed once the rings have been secured with half pins.
2. Planning for spread between the half pins and different insertion angles increases the stability of the construct.

Fig. 2 AP (a) and lateral (b) views of the R leg, showing an applied spatial frame after final adjustments. A near-anatomic reduction has been achieved

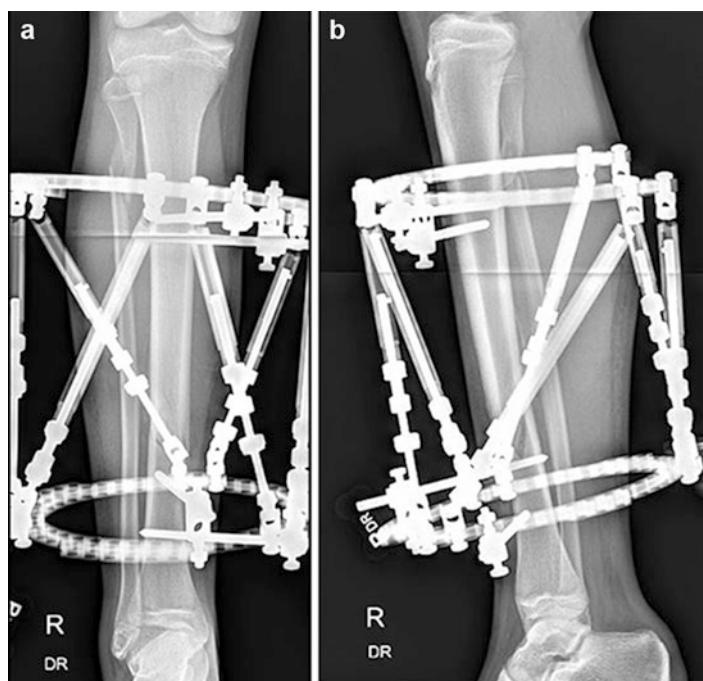




Fig. 3 AP (a) and lateral (b) views of the right leg, showing adequate healing and alignment following removal of the spatial frame

3. Knowledge of the eventual location of the struts helps plan half pin insertion. Initial pins can be placed proximal to the proximal ring and distal to the distal ring out of the path of the proposed struts.
4. If delayed bone healing is observed postoperatively, options include programming the spatial frame to repeatedly compress and distract 1–2 mm at the fracture site (“accordion technique”), or the frame can be dynamized by removing the struts as long as callus is adequate for weight bearing through the fracture site. Do not remove or unlock only one strut. This will induce shear into the fracture site.
5. Adding one or two threaded rods to the frame at the time of frame application will increase the initial stiffness of the construct. These rods can then be removed in a few weeks to start the dynamization process.

8 Outcome Clinical Photos and Radiographs

See Fig. 3

9 Avoiding and Managing Problems

1. Superficial pin site cellulitis can be minimized by ensuring that the skin surrounding the pins is not pulled or stretched (under tension).
2. Superficial pin site cellulitis can typically be treated with routine pin site care and a 7-day course of an oral, first generation cephalosporin.
3. The half pins should not be placed in locations that will impinge on the struts or limit strut movement.
4. Avoid generating heat while drilling the half pins: use sharp drills, drill slowly, do not use a tourniquet, and irrigate the drilling site.

10 Cross-References

- ▶ [Submuscular Plating of Tibial Fractures](#)
- ▶ [Tibial Shaft Fracture: Flexible Nails](#)
- ▶ [Tibial Shaft Fracture: Plating](#)
- ▶ [Tibial Shaft Fracture with Bone Loss](#)
- ▶ [Tibial Shaft Fracture with Soft Tissue Loss](#)
- ▶ [Tibial Shaft Fracture Treated with a Rigid Nail](#)

References and Suggested Reading

- Al-Sayyad MJ (2006) Taylor spatial frame in the treatment of pediatric and adolescent tibial shaft fractures. *J Pediatr Orthop* 26(2):164–170
- Eidelman M, Katzman A (2008) Treatment of complex tibial fractures in children with the taylor spatial frame. *Orthopedics* 31(10), PMID:19226013
- Henderson DJ, Barron E, Hadland Y, Sharma HK (2015) Functional outcomes after tibial shaft fractures treated using the Taylor spatial frame. *J Orthop Trauma* 29(2):e54–e59
- Tucker HL, Kendra JC, Kinnebrew TE (1992) Management of unstable open and closed tibial fractures using the Ilizarov method. *Clin Orthop Relat Res* 280:125–135

Tibial Shaft Fracture with Soft Tissue Loss

Brian E. Kaufman

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Abstract

Accounting for nearly 15% of all long bone fractures in children, tibial shaft fractures are common in the pediatric population. Limited natural history studies have shown that approximately 10% of pediatric tibial shaft fractures will be open. Injuries requiring soft tissue coverage are even less common with Gustilo 3B and 3C injuries occurring in 7–10% and 2.6% of all open pediatric tibia fractures, respectively. The surgeon should be aware of the nearly 10% rate of compartment syndrome in open tibial shaft fractures and perform careful, frequent neurovascular evaluations of the injured limb. Treatment of these rare, but potentially limb-threatening, injuries generally follows adult open tibia fracture guidelines. The focus should be on prompt administration of antibiotics, urgent to emergent wound debridement and

irrigation, bony stabilization, and early soft tissue coverage. The advent of hexapod external fixators has improved the options for bony stabilization and may allow for residual correction of angular and rotational deformities. Regardless of the method of treatment, time to healing can exceed 20 weeks.

1 Brief Clinical History

The patient is a 14-year-old male who was the unhelmeted passenger on a dirt bike that was struck by a car. He sustained a closed right femur fracture and a segmental right tibia fracture with significant bone and soft tissue loss (Figs. 1a, b and 2). Upon arrival to the emergency department, tetanus prophylaxis and antibiotic coverage with Ancef, Gentamicin, and Penicillin G were administered due to gross contamination of the wound. The right foot was warm and well perfused with intact dorsalis pedis and posterior tibial artery pulses. The patient was intubated for stabilization before a neurologic exam could be performed. The patient was brought

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Fig. 1 (a, b) Preoperative AP and lateral radiographs demonstrating a segmental right tibia fracture and a transverse fibular diaphyseal fracture

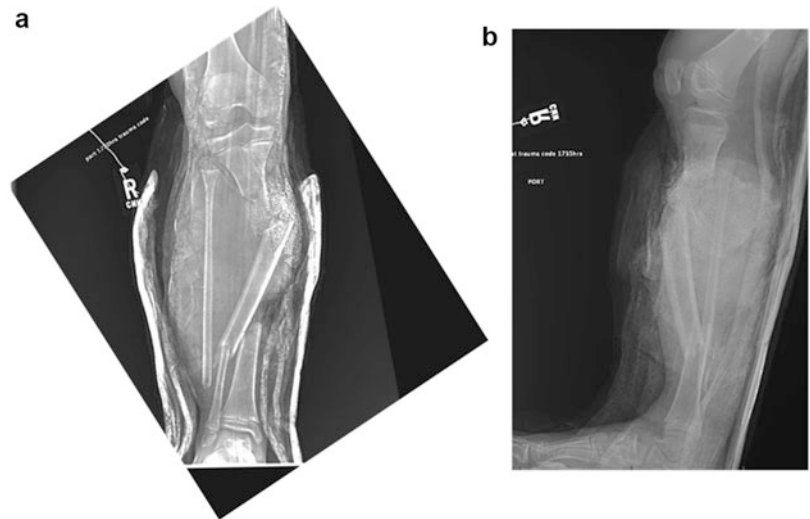


Fig. 2 Intraoperative photograph demonstrating a Gustilo 3B open tibia fracture with significant degloving and exposed tibial fracture fragments

emergently to the operating room where he underwent flexible nailing of his femur fracture and debridement, irrigation, insertion of antibiotic beads, and external fixation of his tibia fracture (Fig. 3a, b). Intraoperatively, the open fracture was classified as a Gustilo 3B injury. Soft tissue coverage of the tibial shaft was provided with a local soleus muscle flap (Fig. 3c, d). Due to the severe degloving nature of the injury, the patient was left with a 15×5 cm skin defect. This wound was initially covered with a negative pressure dressing. After adequate granulation tissue had formed (Fig. 4), a split thickness autograft was utilized to cover the skin defect. Unfortunately, this patient developed a nonunion requiring treatment with a multiplanar external fixator. His course was further complicated by post-traumatic distal femoral and distal tibial valgus deformities treated with medial hemiepiphyseodeses of the distal femur and distal tibia. Ultimately, his fracture healed, and his mechanical alignment was corrected (Fig. 5a–e). At final follow-up 18 months post-injury, the patient was running and jumping without pain or discomfort.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Gustilo 3B open segmental right tibial fracture and transverse diaphyseal fibular fracture with significant soft tissue loss and skin degloving
2. Transverse right femoral shaft fracture

4 Treatment Strategy

In order to minimize the risk of infection in the setting of severe soft tissue injury, antibiotics are promptly administered upon arrival to the emergency department. At our institution, fractures with severe soft tissue injuries are taken emergently to the operating room for debridement, irrigation, and, at minimum, provisional fracture stabilization. Debridement of gross contamination of the wound bed and fracture edges should be accomplished prior to irrigation. Low-pressure saline irrigation is preferred by the author as no definitive benefit has been found to high-pressure irrigation or the addition of antibiotics to the irrigant solution. The wound is typically irrigated until clean with a minimum of 3 liters of saline utilized. Antibiotic impregnated polymethylmethacrylate (PMMA) cement beads or spacers can be helpful adjuncts to systemic antibiotics in large soft tissue defects.

Attention is then turned to stabilizing the fracture. When primary soft tissue coverage is possible, intramedullary nails

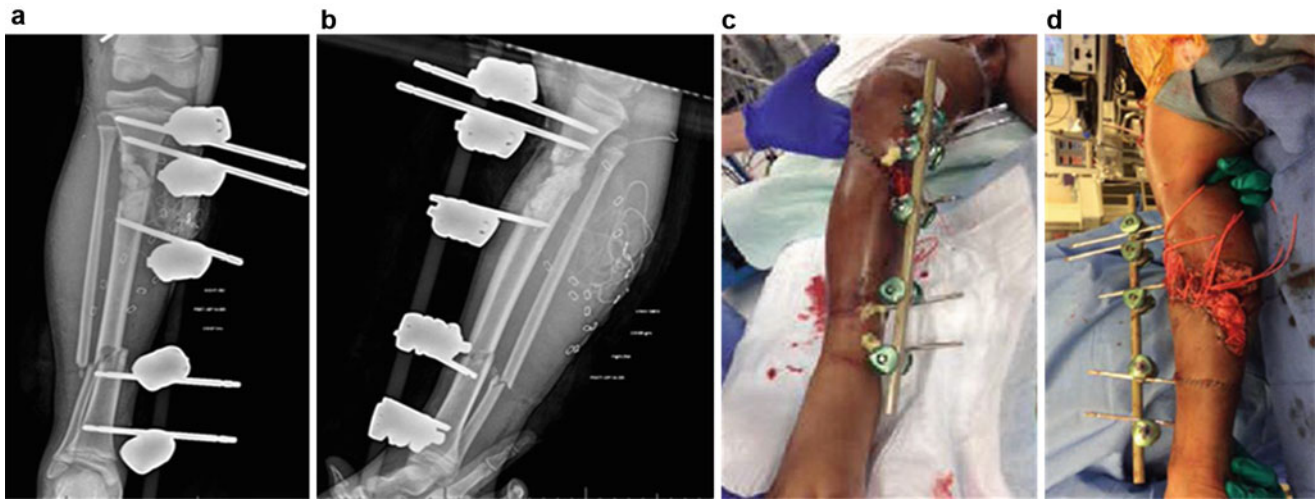


Fig. 3 (a–d) Postoperative AP and lateral radiographs (a, b) after external fixation and insertion of antibiotic beads. Intraoperative clinical photographs (c, d) after local soleus muscle flap and partial skin closure

or plate fixation may be utilized. In these instances, the choice of fixation is dependent on the pattern of the fracture. When soft tissue loss prevents primary closure, external fixation provides excellent bony stability and may be used as the definitive method of treatment. The use of unilateral or hexapod frames is left to the surgeon's preference. It is possible to temporarily stabilize a fracture with unilateral fixation and later convert the patient to a hexapod fixator at the time of definitive soft tissue coverage. Pin and/or wire placement should be extra-physeal and, if possible, should avoid the immediate zone of soft tissue injury.

As much soft tissue coverage of the fracture as is possible should be attained at the time of initial operative intervention. Local rotational flaps, such as of the gastrocnemius or soleus, may be employed. In the absence of locally available soft tissues, negative pressure wound therapy can be initiated. Large soft tissue wounds typically require multiple trips to the operating room for secondary debridement and irrigation with definitive soft tissue coverage ideally occurring in less than 1 week.

5 Basic Principles

1. Administration of antibiotics greater than 3 h after injury has been demonstrated to significantly increase the risk of infection in open fractures (Patzakis and Wilkins 1989).
2. For non-contaminated open fractures, first generation cephalosporins provided adequate antibiotic coverage. Some authors will advocate for the use of gram-negative coverage in severe wounds. Penicillin G is reserved for grossly contaminated wounds to prevent clostridial myonecrosis (Melvin et al. 2010b).
3. In accordance with Gustilo and Anderson's initial recommendations, the classifying of open fractures occurs in the operating room (Gustilo and Anderson 1976). The skin laceration may underestimate the degree of soft tissue and periosteal stripping at the level of the fracture. This point is particularly relevant in tibial shaft fractures in which there is little soft tissue coverage anteromedially.
4. Initial surgical management of the soft tissue wound should consist of prompt, thorough debridement and irrigation. Locally delivered antibiotics have limited morbidity and can reduce the risk of local infection (Melvin et al. 2010b).
5. Whenever possible, primary repair of the soft tissue should be attempted in a tension-free manner. Temporary

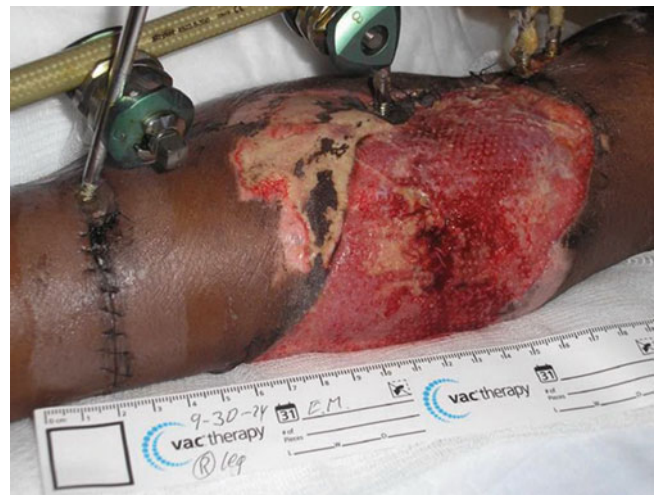


Fig. 4 Anterolateral tibial wound after 2 weeks of negative pressure therapy prior to split thickness skin grafting

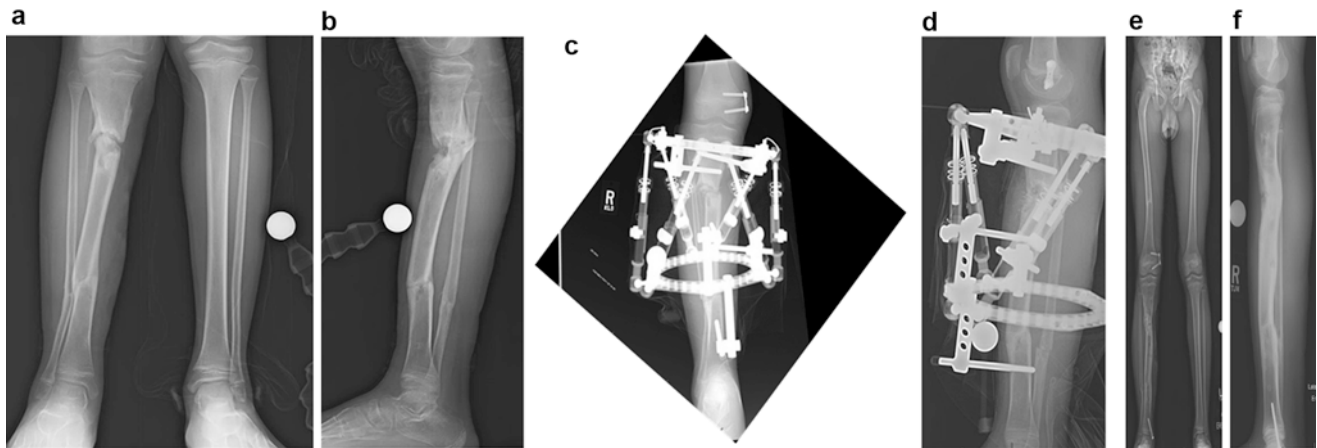


Fig. 5 (a–f) AP and lateral radiographs of the right leg (a, b) 8 months post-injury demonstrating nonunion of the proximal tibial fracture with valgus and recurvatum deformities. Immediate postoperative radiographs of the right leg (c, d) after tibial and fibular osteotomy, bone

grafting, and medial distal femoral hemiepiphysiodesis. Full-length lower extremity AP and right leg lateral radiographs (e, f) at final follow-up 18 months post-injury demonstrating healed tibial and fibular fractures with restoration of the mechanical axis

soft tissue coverage can be provided with negative pressure wound therapy. If necessary, rotational or free-flap coverage should occur within 7–10 days so as to minimize the risk of infection (Shapiro et al. 1989; Melvin et al. 2010a).

6. In severe soft tissue wounds (Gustilo 3B and 3C), bony stabilization can be achieved with unilateral or hexapod frames. In the setting of segmental bone loss, pediatric patients can tolerate greater than 3 cm of shortening to achieve soft tissue closure with planned lengthening after healing (Laine et al. 2016). Intentional deformation of the fracture to allow wound closure can also be performed with a hexapod external fixator (Nho et al. 2006). The fracture can be gradually reduced once the soft tissue wound has healed.

3. External fixation pins/wires should not violate the proximal or distal tibial physis so as to decrease the risk of injury to the growth plate. The basic principles of external fixation should still be followed in that pin spread should be maximized and pins should not be placed through the soft tissue zone of injury if at all possible.

8 Outcome Clinical Photos and Radiographs

See Fig. 5.

6 Images During Treatment

See Figs. 3 and 4.

7 Technical Pearls

1. Thorough debridement of devitalized tissues in the wound bed at the time of initial evaluation can minimize the risk of local soft tissue necrosis.
2. Locally applied PMMA antibiotic cement beads should be 5–10 mm in diameter to maximize elution potential. The beads should be strung on a nonabsorbable suture or wire. The number of beads implanted should be part of the operative report to ensure no beads are left behind at the time of definitive soft tissue closure.

9 Avoiding and Managing Problems

1. The infection rate of open tibia fractures can be as high as 16%. Best practices to minimize the risk of infection include early antibiotic administration and soft tissue coverage. Data from the pediatric literature is limited, but coverage within 1 week has correlated with improved outcomes (Laine et al. 2016). In the adult literature, early (<72 h) soft tissue coverage has shown benefits (Gopal et al. 2004).
2. The clinician should have a high clinical suspicion for compartment syndrome and recognize that the presence of an open fracture does not indicate an adequate fascial release has been performed. The incidence of compartment syndrome is higher in open fractures than in closed fractures. Compartment syndrome is treated with emergent four-compartment fasciotomy.

3. Bone loss and comminution can lead to limb length discrepancy in addition to angular and rotational deformities. Adequate family counseling should include mention of the potential need for multiple procedures in the future to maintain a well-aligned and functional limb.
4. Ultimate survival of the limb is dependent on achieving adequate soft tissue coverage. The family should be advised that, though rare, amputation may become necessary due to soft tissue compromise.

10 Cross-References

- [Tibial Shaft Fracture Treated with a Circular External Fixator](#)
- [Tibial Shaft Fracture Treated with a Rigid Nail](#)
- [Tibial Shaft Fracture: Cast Treatment](#)

References and Suggested Readings

- Gopal S et al (2004) The functional outcome of severe, open tibial fractures managed with early fixation and flap coverage. *J Bone Joint Surg Br* 86:861–867
- Gustilo RB, Anderson JT (1976) Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. *J Bone Joint Surg Am* 58:453–458
- Laine JC et al (2016) The management of soft tissue and bone loss in type IIIB and IIIC pediatric open tibial fractures. *J Pediatr Orthop* 36:453–458
- Melvin JS et al (2010a) Open tibial shaft fractures: II. Definitive management and limb salvage. *J Am Acad Orthop Surg* 18:108–117
- Melvin JS et al (2010b) Open tibial shaft fractures: I. Evaluation and initial wound management. *J Am Acad Orthop Surg* 18:10–19
- Nho SJ, Helfet DL, Rozbruch SR (2006) Temporary intentional leg shortening and deformation to facilitate wound closure using the Ilizarov/Taylor spatial frame. *J Orthop Trauma* 20:419–424
- Patzakis MJ, Wilkins J (1989) Factors influencing infection rate in open fracture wounds. *Clin Orthop Relat Res* 243:36–40
- Shapiro J et al (1989) Free tissue transfer in children. *J Pediatr Orthop* 9:590–595

Tibial Shaft Fracture with Bone Loss

Marielle Amoli and Jeffrey R. Sawyer

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Abstract

A 12-year-old presented with a grade 3B **open tibial fracture**, bone loss, and a pulseless left lower extremity after he was struck by a car while riding his all-terrain vehicle (ATV). Multiple irrigation and debridements were done and a monolateral external fixator was applied. This was eventually converted to a circular fixator for bone transport, and his tibia healed with a leg-length discrepancy, which was treated with magnetically controlled lengthening at skeletal maturity.

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1 Brief Clinical History

A 12-year-old boy was transferred from an outside hospital with a pulseless left lower extremity after an ATV accident in which he was struck by car; he had no injuries of other extremities, head, neck, or abdomen. He was alert and cooperative during physical examination. His left lower extremity had an approximately 20 × 20 cm wound on the posterior-medial aspect with exposed tibia and gross contamination with grass. Extensor hallucis longus and flexor hallucis longus function was intact. Sensation was decreased over the medial aspect of his leg and foot, but was intact in his toes. Dorsalis pedis and posterior tibialis pulses were nonpalpable. Doppler examination identified a dorsalis pedis pulse, but no posterior tibialis pulse was discernible.

2 Preoperative Clinical Photos and Radiographs

See Fig. [1a, b](#)

Fig. 1 Anteroposterior (a) and lateral (b) radiographs from injury



3 Preoperative Problem List

1. **Grade 3B open left tibial-fibular fractures**
2. Left medial malleolar fracture, nondisplaced
3. Left calcaneal fracture, nondisplaced
4. Left navicular fracture, nondisplaced

4 Treatment Strategy

Limb salvage and primary amputation were discussed with the family. Because the patient had a dorsalis pedis pulse on Doppler examination, the decision was made to attempt limb salvage with urgent irrigation and debridement (I&D)

and external fixator placement on the day of injury. Intraoperatively, the patient was found to have significant tibial bone loss. Serial I&Ds with negative pressure wound therapy were followed by a free latissimus dorsi flap. The decision was made to treat the tibial shaft fracture definitely with external fixation given the degree of wound contamination, presence of a flap, and need for bone transport.

5 Basic Principles

1. Open fractures are complex, challenging injuries that are prone to infection, delayed union, and nonunion.

Fig. 2 Anteroposterior (a) and lateral (b) 3D CT renderings after initial stabilization with placement of temporary monolateral external fixation

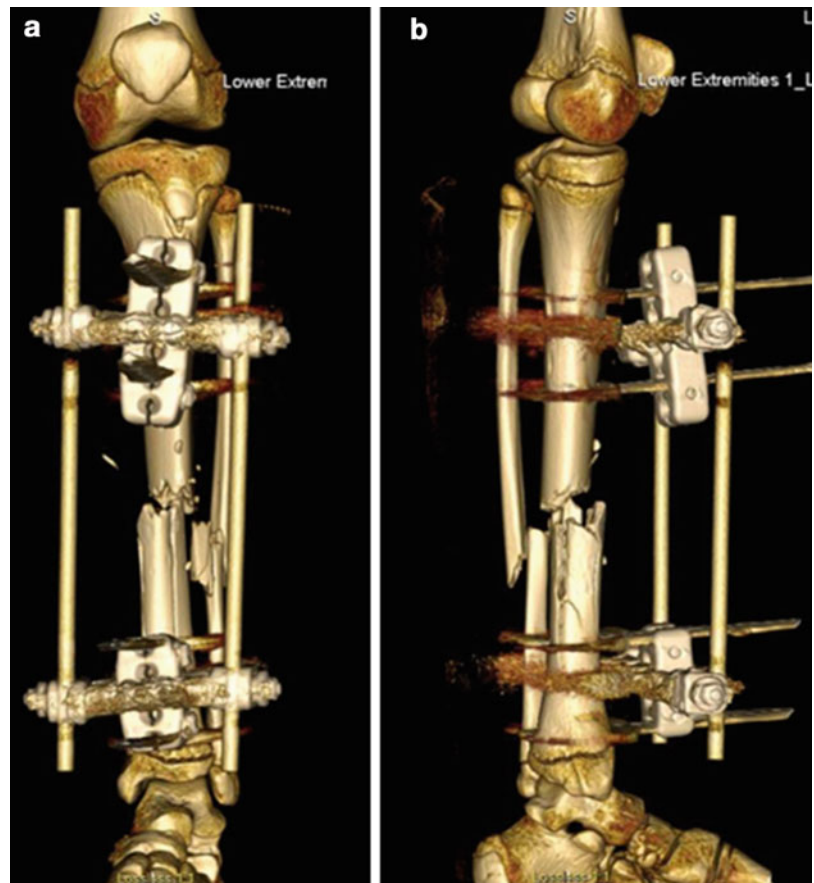
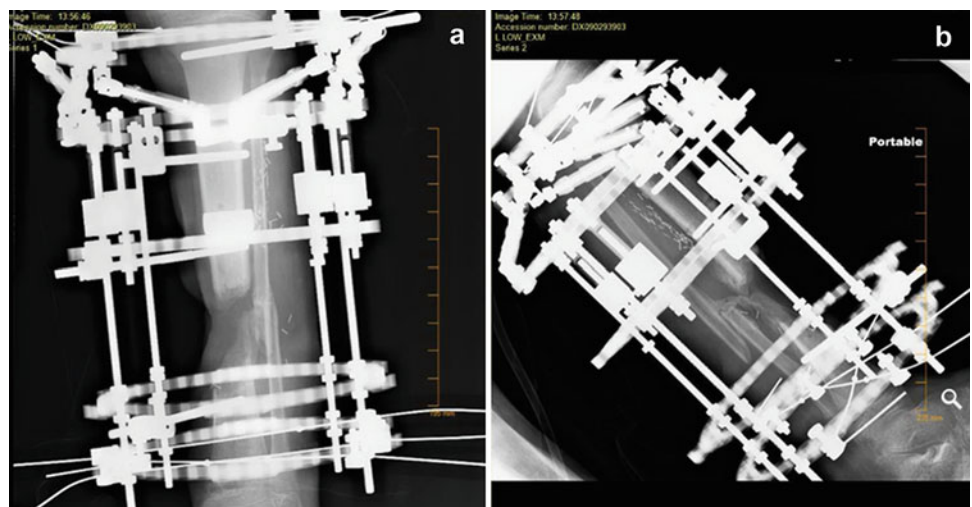


Fig. 3 Anteroposterior (a) and lateral (b) radiographs 1 month after injury when circular external fixator was applied



2. Open fractures should receive immediate attention, prompt administration of broad-spectrum intravenous antibiotics, and I&D in the operating room.
3. Provisional or definitive fracture stabilization and wound closure technique must be decided at the index procedure. In this patient, because of the significant comminution, gross contamination of the wound, and high risk of infection, the decision was made to proceed with external fixation.
4. When there is significant bone loss as well as vascular injury, as in this patient, the decision to proceed with limb salvage versus amputation adds another challenge.
5. **External fixation** choices include monolateral and circular external fixation. Monolateral external fixation

offers the advantage of ease of application, but with risks of loss of reduction and malunion. Circular external fixation is more technically challenging, but allows more stability and correction of limb-length inequalities or angular deformities as well as bone transport.

5.1 Images During Treatment

See Fig. 2.

5.2 Images, Clinical Photos, or Radiographs (Fig. 3)

One month after injury, he developed drainage from his fracture and pin sites. Intraoperative cultures were positive

for *Proteus mirabilis*, *Chromobacterium violaceum*, and *Candida parapsilosis*. Again treatment options were discussed with parents including the use of antibiotic spacer, versus acute shortening versus bone transport. Due to the significant projected leg-length discrepancy that would result with acute shortening, parents elected to proceed with bone transport. For this reason, patient underwent repeat I&D, removal of devitalized bone, and treatment with IV antibiotics; no antibiotic spacer was used. In addition, the monolateral fixator was replaced with a circular fixator, which provided stable tibial fixation and allowed local wound care and lengthening to correct the bone loss.

Fig. 4 Anteroposterior (a) and lateral (b) radiographs after bone transport to correct for the amount of bone loss from injury and debridement of devitalized bone

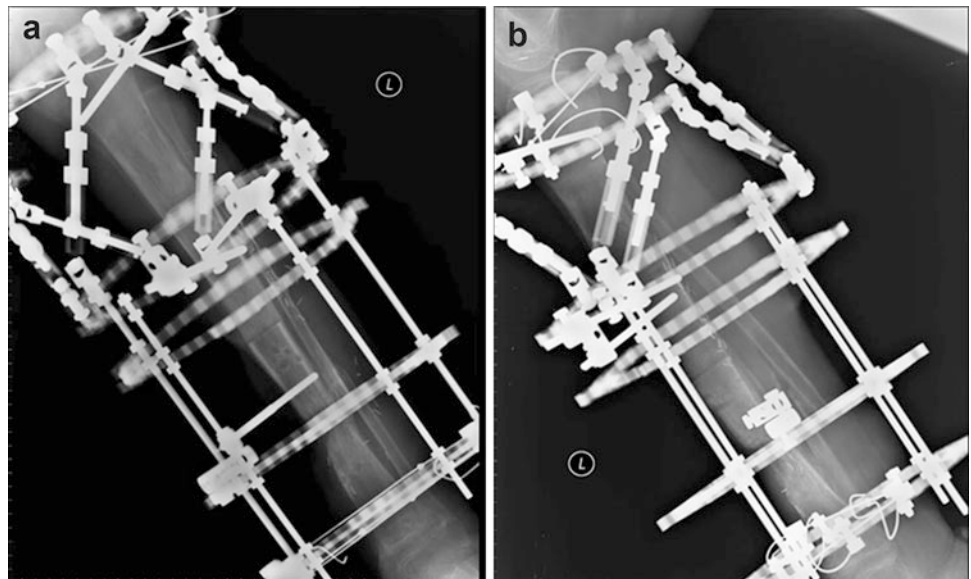


Fig. 5 After fracture union, patient returned to full activity, including high school baseball

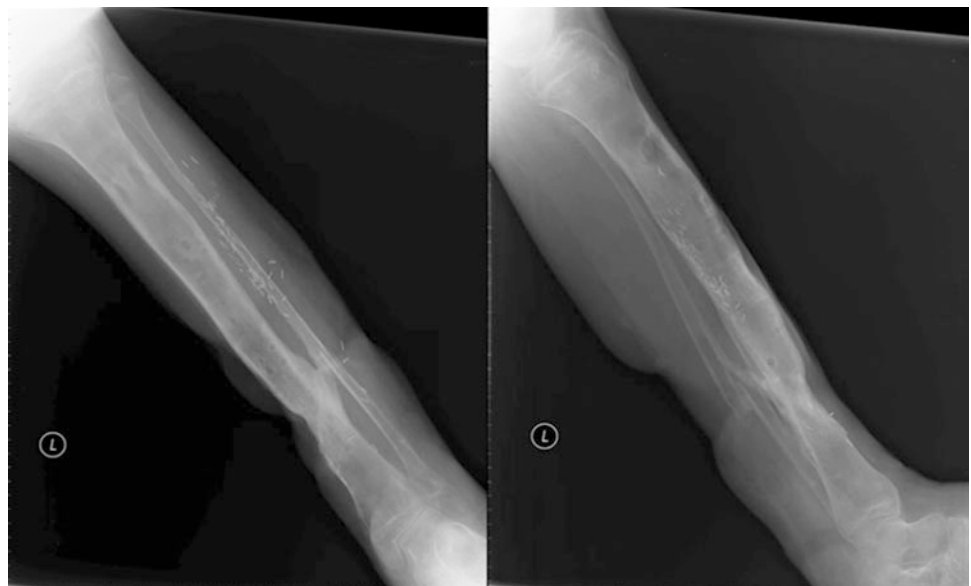


Fig. 6 Patient returned 7 years later at skeletal maturity, complaining of slightly decreased range of motion in the *left* ankle and a limb-length discrepancy of 4 cm for which he had been using a shoe lift with moderate improvement. He elected to proceed with left lower extremity lengthening using a PRECISE intramedullary tibial nail



Fig. 7 Patient was successfully lengthened 4 cm with a PRECISE intramedullary tibial nail. He has started college, is doing well clinically, and is pleased with his outcome

6 Technical Pearls

1. Timely IV antibiotic administration based on wound severity.
2. Complete physical and radiographic examinations to check for concomitant injuries
3. Thorough I&D in the operating room at index procedure, including debridement of devitalized bone
4. Understanding of the roles of monolateral (temporary fixation) versus circular external fixation (definitive fixation)
5. Treatment with circular external fixation via hexapod or Ilizarov technique for correction of deformity and bone transport when there is bone loss
6. High index of suspicion for deep infection if wound or pin site drainage, fever, or other signs of infection develop

7 Outcome Clinical Photos and Radiographs

See Figs. 4–7

8 Avoiding and Managing Problems

1. The frequency of pin site infections can be minimized with proper pin site care. It is important to educate patients and their family on the signs and symptoms of a pin track infection. Close monitoring of pin sites in clinic is recommended. Providing a prophylactic antibiotic prescription is helpful.
2. A low threshold for treating superficial pin site infections is necessary to avoid deep infections. If deeper infection develops, returning to the operating room for I&D and possible pin exchange should be considered.
3. Delayed union may occur at the docking site. Just prior to docking, a return trip to the OR for bone grafting and re-freshening of the bone ends is helpful. Maximizing to surface area of bone contact between the fragments is critical. Dynamization of the frame and weight bearing by the patient is necessary to train the bone and accelerate the healing process.

4. When external fixation is used, it is important to regularly monitor radiographic healing. If a fracture loses reduction, an angular deformity may develop and lead to a malunion. If loss of reduction is noted early, the monolateral frame can be adjusted or, when using a hexapod-type fixator, a total residual program can be used to correct the deformity.

9 Cross-References

- [Tibial Shaft Fracture Treated with a Circular External Fixator](#)
- [Tibial Shaft Fracture with Soft Tissue Loss](#)
- [Tibial Shaft Fracture: Plating](#)

References and Suggested Readings

- Al-Sayyad MJ (2006) Taylor spatial frame in the treatment of pediatric and adolescent tibial shaft fractures. *J Pediatr Orthop* 26(2):164–170
- Buckley SL, Smith GR, Sponseller PD, Thompson JD, Robertson WW, Griffin PP (1996) Severe (type III) open fractures of the tibia in children. *J Pediatr Orthop* 16(5):627–634
- Tafazal S, Madan SS, Ali F, Padman M, Swift S, Jones S, Fernandes JA (2014) Management of paediatric tibial fractures using two types of circular external fixator: Taylor spatial frame and Ilizarov circular fixator. *J Child Orthop* 8(3):273–279

Tibial Shaft Stress Fracture

Jason Read and Eric D. Shirley

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Abstract

A 15-year-old male initially presented with left lower leg pain and radiographs consistent with an anterior tibial cortex stress fracture. Pain persisted despite nonoperative measures including rest from activities and protected weight-bearing. Surgical treatment was offered and the patient underwent intramedullary (IM) nailing of the left tibia shaft stress fracture as this option allowed immediate weight-bearing. The stress fracture healed uneventfully within 5 months.

1 Brief Clinical History

A 15-year-old male elite ballet dancer presented with several months of anterior left lower leg pain. Initial radiographs were suspicious for an anterior tibial cortical stress fracture. Magnetic resonance imaging (MRI) confirmed anterior tibial stress fracture. Nonoperative management was initiated including rest from dance activities, tibial fracture brace, and protected weight-bearing. Patient was initially able to return to dance activities after conservative treatment; however, symptoms later returned. Repeat radiographs and MRI confirmed a persistent anterior tibial stress fracture. Surgery was offered to alleviate symptoms and achieve fracture union.

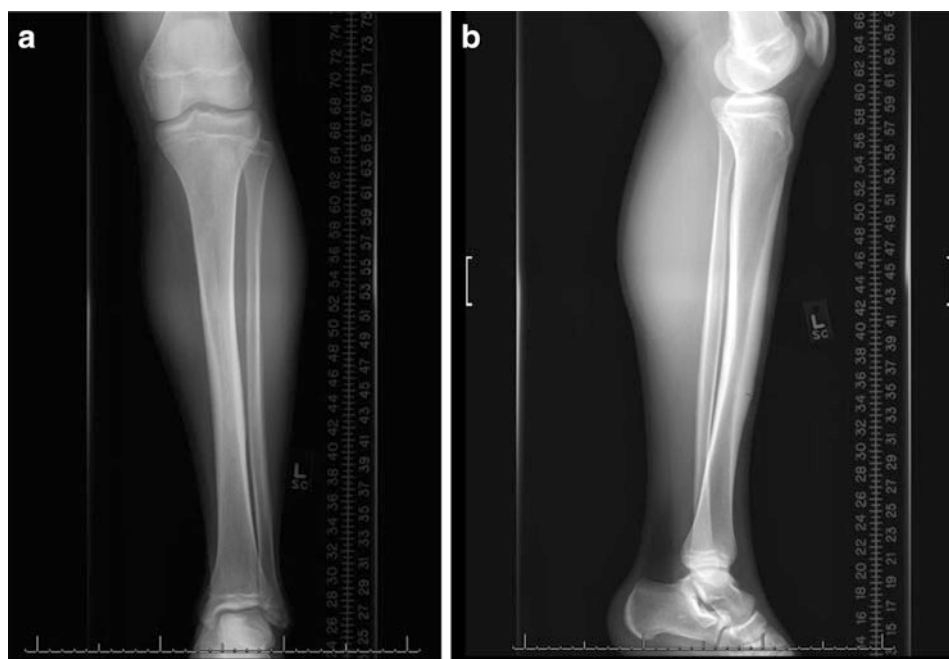
2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

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Fig. 1 AP (a) and lateral (b) radiograph of the left tibia. Cortical thickening is seen at the mid shaft of the tibia on the AP view and a transverse lucency of the anterior tibial cortex below the mid diaphysis is seen on the lateral view



3 Preoperative Problem List

1. Leg pain
2. Anterior tibial stress fracture

4 Treatment Strategy

Tibial stress fractures are divided into two subclasses based on the location of the stress fracture, the posteromedial tibial cortex and the anterior tibial cortex. Treatment options are guided by the location of the stress fracture. Posteromedial cortex tibial stress fracture can be treated with nonoperative management including activity modifications and protected weight-bearing. Anterior tibial cortex stress fractures have a higher risk of nonunion or delayed healing and may be more likely to require surgical management. IM nailing allows for immediate weight-bearing and rapid recovery.

5 Basic Principles

1. Characteristics of tibial shaft stress fractures usually include a history of a repetitive trauma from a particular sports or activity and symptoms that worsen as weight-bearing increases. Pain typically occurs during the day and with activities along with absence of pain.
2. Night pain raises suspicion of another cause such as an osteoid osteoma, chronic osteomyelitis, and Ewing sarcoma.
3. Stress fractures require careful consideration of the training regimen and potential co-morbid conditions (such as endocrine disease or malabsorption). In addition, intake of calcium, vitamin D, and protein should be evaluated with a complete metabolic panel and vitamin D levels. A menstrual history with or without hormonal levels is important in females to identify the female athlete triad.
4. The physical examination in patients with a tibial stress fracture includes identifying risk factors such as lower limb malalignment, forefoot varus, and hyperpronation.
5. Initial imaging studies should include AP and lateral radiographs of the lower leg. Radiographic changes may not be apparent until 2–4 weeks after the initial onset of pain. Changes on x-ray include sclerosis, periosteal elevation, cortical thickening, and a radiolucent cortical fracture line.
6. If additional imaging studies are needed, MRI provides the highest sensitivity and specificity compared with CT or a bone scan.
7. Nonoperative treatment of tibial stress fractures consists of nonweight-bearing or protected weight bearing with activity modifications and pain control. Patients may require nonweight-bearing initially to reduce pain. Protected weight-bearing may include a cam walker boot, short leg cast, and crutches for a period of 4–6 weeks. Alternative therapy includes bone stimulators; however, current evidence suggests no reduction in pain or healing time.
8. If nonoperative treatment fails, surgical treatment with an IM nail is an option in patients with closed tibial physes.

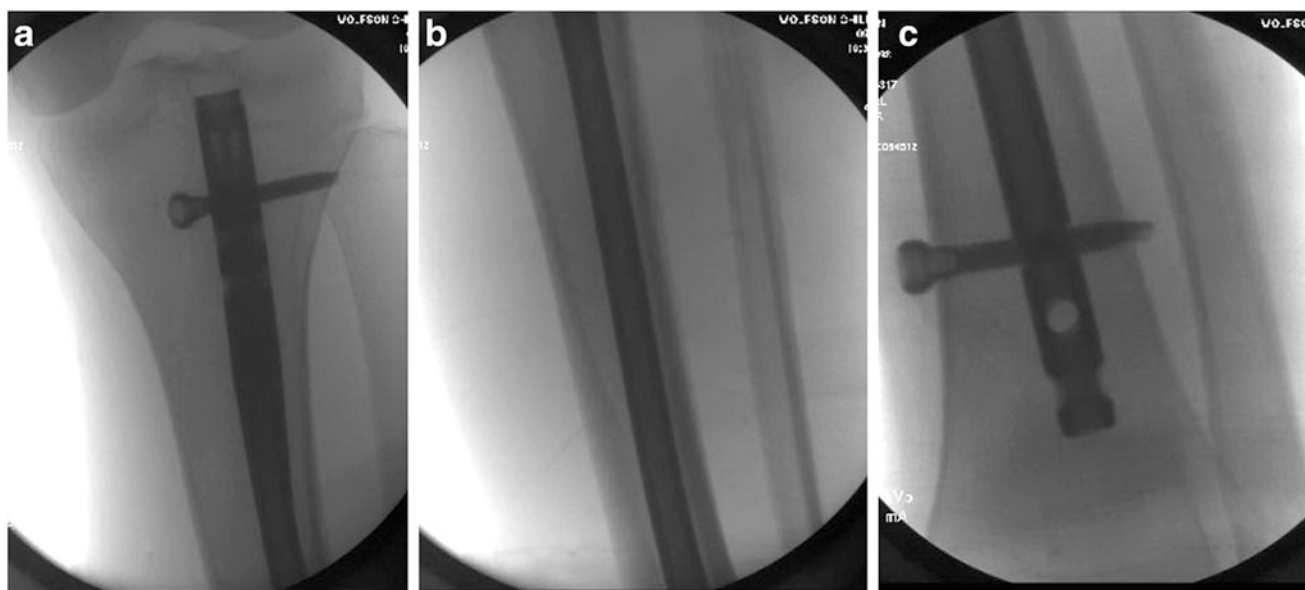


Fig. 2 Intraoperative fluoroscopy AP images of the proximal (a), shaft (b), and distal (c) left tibia after IM nail insertion

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

1. An appropriate radiolucent operating table is selected.
2. After proximal reaming, a guide pin is inserted across the fracture.
3. Reaming is performed until cortical chatter is achieved. Venting the canal can decrease the risk of fat embolism from reamer a closed canal.
4. The largest nail that can safely be inserted is utilized.
5. Proximal and distal interlocks are utilized for rotational control.
6. Weight-bearing as allowed after surgery.

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

1. X-ray imaging is an appropriate initial approach when concerned for tibial stress fracture. Followup x-rays will usually show healing of the fracture with callus formation in most cases. If initial x-rays are negative but there is high suspicion for a stress fractures, further imaging studies

- include a bone scan, CT scan, and MRI with MRI having the highest sensitivity and specificity. A bone scan may be useful in initial evaluation given its higher sensitivity or if there are particular concerns for multiple areas of stress fractures. However, a bone scan will also be positive in cases of infections or tumor and for followup imaging studies may not be as useful as a bone scans can remain positive for over a year. In the acute setting when assessing for a tibial stress fracture, CT scan may not be as useful given lower sensitivities than an MRI and bone scan. CT scans, however, are useful in assessing healing of a diagnosed stress fractures when there are concerns for treatment failure including if the fracture has extended or developed a nonunion.
2. The differential diagnosis for tibial stress fractures incorporate a variety of conditions including medial tibial stress syndrome, compartment syndrome, pes anserine bursitis, Osgood-Schlatter disease, posterior tibial tendinitis, and other bony processes including bone cysts, tumors, osteoid osteoma, and infection. Given broad spectrum of other bony processes, a biopsy may be needed to rule out other possible bone conditions along with infectious disease labs including CBC, ESR, and CRP to rule out infectious causes such as osteomyelitis.
3. Posterior medial and anterior cortex tibial stress fractures can both be treated with nonoperative measures. Anterior cortex tibial stress fractures are often slow to heal, often develop nonunion, and are at risk of recurrence. When nonoperative measures are used, treatment is typically to remove the offending impact activity. However, there are differences in this treatment between the two types of stress fractures. Posterior medial tibial stress fractures are often allowed to continue to participate in limited activity with protected weight bearing and as pain allows, whereas anterior cortex tibial

Fig. 3 The patient returned to ballet at 2 months after surgery. AP (a) and lateral (b) radiographs at 6 month follow-up demonstrate complete healing of the anterior tibial stress fracture



stress fractures are made nonweight-bearing with no participation in activities. Activity modification and pain management are usually sufficient when treating posterior medial cortex tibial stress fractures. Strict activity modifications with nonweight-bearing for 2–3 months can be trialed with anterior tibial cortex stress fractures but may still result in a clinical outcome of a nonunion.

- [Tibial Shaft Fracture: Plating](#)
- [Tibial Shaft Fracture Treated with a Rigid Nail](#)

10 Cross-References

- [Submuscular Plating of Tibial Fractures](#)
- [Tibial Shaft Fracture: Flexible Nails](#)

References and Suggested Reading

- Markolf KL, Cheung E, Joshi NB, Boguszewski DV, Petrigliano FA, McAllister DR (2016) Plate versus intramedullary nail fixation of anterior tibial stress fractures: a biomechanical study. *Am J Sports Med* 44:1590–1596
- Miyamoto RG, Dhotar HS, Rose DJ, Egol K (2009) Surgical treatment of refractory tibial stress fractures in elite dancers: a case series. *Am J Sports Med* 37:1150–1154

Compartment Syndrome of the Leg

Matthew Stepanovich and Joseph B. Slakey

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Abstract

A 13-year-old male sustained closed diaphyseal tibia and fibula fracture. Due to the inability to maintain reduction and presence of open physes, he underwent closed reduction and flexible nail fixation. Initially, the patient's leg compartments were soft and supple, but postoperatively, he developed increasing pain with paresthesias and was diagnosed clinically with leg compartment syndrome. Intraoperative compartment pressures confirmed the clinical diagnosis requiring four-compartment leg fasciotomy. He later underwent delayed closure.

1 Brief Clinical History

A 13-year-old male sustained isolated closed diaphyseal tibia and fibula fractures while playing at a trampoline park. On arrival to the emergency department, his leg compartments were soft, and he was neurovascularly intact. A single attempt at closed reduction and long leg valved casting was unsuccessful due to fracture instability. Given his open tibial physis and length-stable fracture pattern, we proceeded with closed reduction and flexible nail fixation. On the day of injury, his fracture was closed reduced, and antegrade flexible nails were passed under fluoroscopy on first attempt. Following fixation, his leg compartments remained soft and supple. Approximately 8 h following surgery, the patient began having increasing pain medication requirements and foot and toe paresthesia and was found clinically to have tense leg compartments and pain with passive stretch of all compartments. He was taken emergently for two-incision four-compartment leg fasciotomy with negative-pressure wound therapy closure for both incisions. At the time of his initial release and all subsequent operations, all of this muscle remained well

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Fig. 1 AP (a) and lateral (b) views demonstrate the same level diaphyseal tibia and fibula fractures. The short oblique fracture pattern allowed length stability with intramedullary flexible nailing. Note the open tibial physis



perfused and viable. After serial washouts and attempted closure, his medial wound was closed primarily, and his lateral wound had split-thickness skin grafting for definitive management. Following fasciotomy, all paresthesias resolved, and he had no permanent neurologic deficit. His fracture alignment was maintained throughout his treatment course, and interval radiographs demonstrated routine osseous healing.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

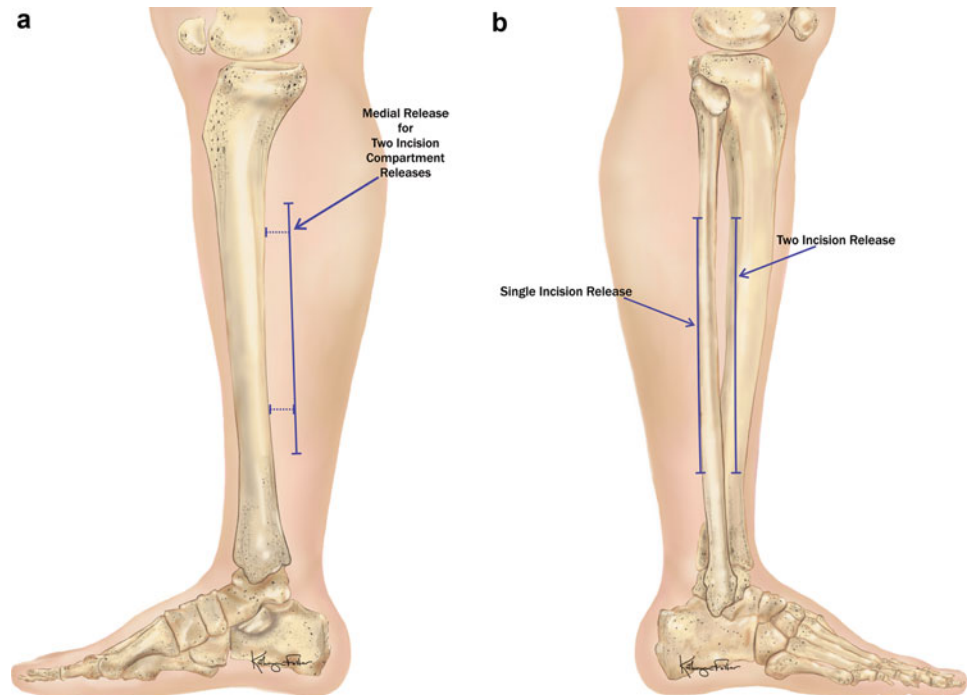
1. Closed adolescent tibia and fibula diaphyseal fracture
2. Diagnosis of compartment syndrome
3. Surgical technique for four-compartment leg fasciotomies
4. Post-fasciotomy wound management and fracture stabilization

4 Treatment Strategy

An initial attempt was made at nonoperative closed reduction and casting for his isolated closed diaphyseal tibia and fibula fractures. Inability to obtain and maintain fracture reduction with casting necessitated operative fixation. Many options for surgical stabilization exist, but given his age and open physis,

as well as the length-stable fracture pattern, treatment with closed reduction and flexible nail fixation was performed utilizing standard medial and lateral antegrade technique. A high index of suspicion for compartment syndrome was maintained, and throughout the surgery, the leg compartments remained soft and supple. Postoperatively, however, the patient had increasing pain medication requirements. On reexamination, the patient had tense leg compartments and pain with passive stretch of his toes, foot, and ankle corresponding to each compartment. A clinical diagnosis of leg compartment syndrome was made. The patient was taken for emergent four-compartment leg fasciotomies. A two-incision release was performed through standard posteromedial and anterolateral incisions. In traumatic compartment syndrome, it is essential that both the skin incision and fascia releases are long enough to allow complete compartmental decompression. All four compartments in the leg should be released: anterior, lateral, superficial posterior, and deep posterior. Through the lateral incision, the anterior intermuscular septum acts as an anatomical guide to both the anterior and lateral compartments. During lateral release, it is imperative to be aware of and protect the superficial peroneal nerve as it typically traverses the fascia from deep in the lateral compartment to superficial anteriorly. Through the medial incision, both the deep and superficial posterior compartments are released. The saphenous nerve and greater saphenous vein must be identified and protected. It is best to release the posterior compartment moving from distal to proximal. As the release progresses proximally, the soleus muscle origin off of the posterior medial tibia regularly needs to be partially released to allow complete deep posterior compartment fasciotomy. After completion of releases, the

Fig. 2 Incisions used for fasciotomy. **(a)** Medial incision is placed at least 1 centimeter from the posterior border of the tibia. **(b)** The incision for the lateral one-incision technique is placed directly over the fibula, while the two-incision technique incision is placed midway between the tibia and fibula



muscles of each compartment should be inspected and verified to be healthy and viable. Muscle viability should be assessed by evaluating the muscle color, consistency, capacity to bleed, and contractility with mechanical grasping or electrocautery. The wounds should be covered with sterile dressings until delayed definitive closure can be completed.

5 Basic Principles

1. By being aware of the possibility of compartment syndrome for any tibia fracture and using this treatment method, the diagnosis of acute leg compartment syndrome was made quickly, and emergent fasciotomies were completed prior to tissue death and function loss.
2. Diagnosis of compartment syndrome is primarily a clinical diagnosis in an awake patient; however, in polytrauma patients, in obtunded patients, or for intraoperative diagnosis, numerous compartment pressure measuring devices are available (Bae et al. 2001).
3. The two-incision method was utilized in this case, but a directly lateral incision can be utilized for a one-incision four-compartment fasciotomy. Multiple techniques for single-incision compartmental release have been published including the parafibular approach, as depicted in Fig. 3, and more recently the paratibial approach that utilizes lateral retraction of the tibialis anterior muscle to gain access and release the deep posterior compartment (Maheshwari et al. 2008; Ebraheim et al. 2016). Regardless of the approach, each affected compartment must be

completely released. Both approaches have advantages and disadvantages. Ultimately, the treating surgeon's comfort and the patient's soft tissue condition should determine which approach is utilized.

4. Following fasciotomy, sterile dressing application for soft tissue rest and coverage is applied.
5. Final closure is ideally completed with delayed primary closure, but the use of split-thickness skin grafting over the lateral wound is a great alternative when required.

6 Images During Treatment

See Figs. 2, 3, 4, and 5.

7 Technical Pearls

1. Early recognition and emergent treatment of pediatric leg compartment syndrome remain the pillars of management.
2. The combination of increasing pain, commonly documented with increasing analgesia requirement, with increasing patient agitation and/or anxiety all serve as sensitive clinical indicators of compartment syndrome in the pediatric population (Noonan and McCarthy 2010).
3. Certain injury and fracture patterns predispose patients to developing compartment syndrome in individual compartments. This is clearly demonstrated with tibial tubercle fractures leading to isolated anterior leg compartment syndrome due to specific blood vessel injury.

Fig. 3 Axial views demonstrating the skin incision location and compartment releases for a one-incision (c) and two-incision (d) technique

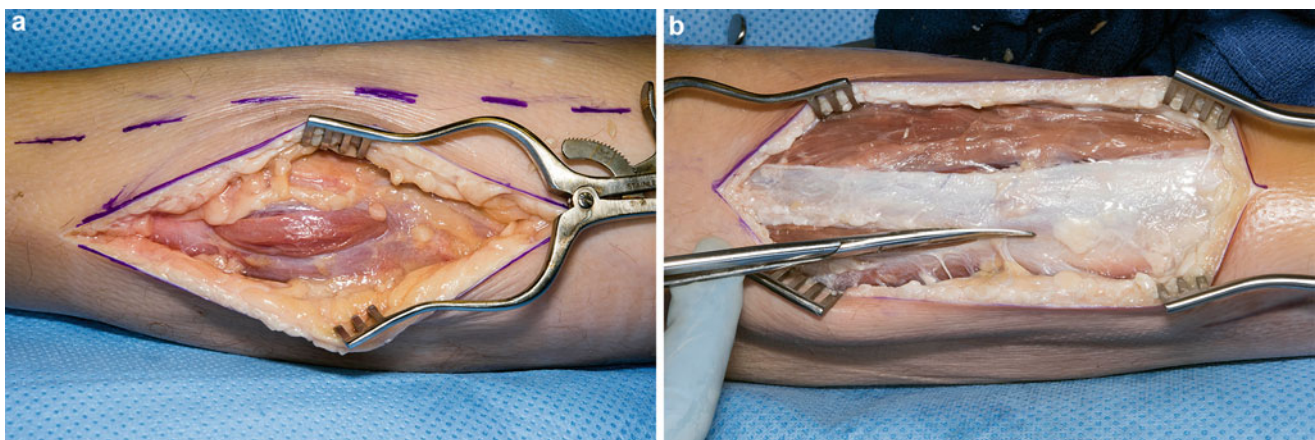
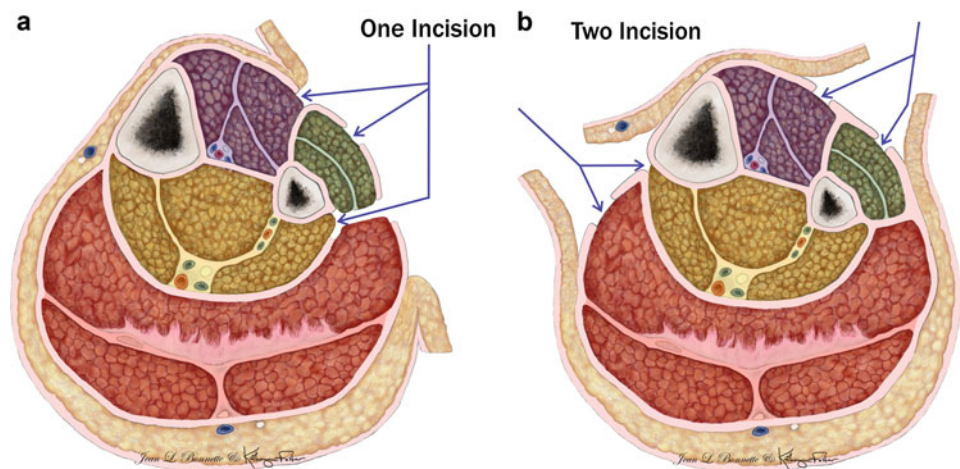


Fig. 4 Cadaveric dissections demonstrating two-incision leg fasciotomy. Note the start of the posterior superficial compartment release medially (a) and a lateral compartment fasciotomy following a previously released anterior compartment (b)

4. If clinical uncertainty of compartment syndrome diagnosis arises, all four leg compartment pressures should be measured and documented. If a fracture is present, the measurement should be made within 5 cm of the fracture site. If measurement is made intraoperatively, the reading must be compared to the patient's preoperative diastolic blood pressure, and values less than 20–30 mmHg are considered diagnostic. The Stryker monitor (Stryker Corporation, Kalamazoo, MI) is utilized at our facility, but regardless of the device, the treating surgeon must be familiar with the location and operational technique of their individual device (Heckman et al. 1994; Kakar et al. 2007).
5. In traumatic leg compartment syndrome, minimally invasive skin incisions are not indicated, and complete compartment release should be visualized and completed.
6. Post-fasciotomy soft tissue management can be time-consuming and challenging. All attempts should be made to close the medial incision over the tibia primarily, and if required, small relaxing skin incisions or split-

thickness skin grafting can be effectively utilized for lateral soft tissue defects. Preparing the patient and family for potential skin grafting early in the treatment course may allow for definitive soft tissue management earlier and potentially prevent repeated trips to the operating room.

8 Outcome Clinical Photos and Radiographs

See Fig. 6.

9 Avoiding and Managing Problems

1. Early recognition and diagnosis postoperatively allowed emergent fasciotomies to be completed prior to tissue death and function loss.
2. Additional non-circumferential immobilization with plaster splinting with the foot in neutral following

Fig. 5 AP (a) and lateral (b) radiographs during treatment demonstrate restoration of length and alignment with flexible nail fixation of the diaphyseal tibia fracture. Note the three-sided splint immobilization to add additional fracture support. Staples denote area of lateral split-thickness skin grafting



Fig. 6 AP (a) and lateral (b) radiographs at follow-up showing maintained alignment and interval healing of his diaphyseal tibia and fibula fractures



fasciotomies allowed continued fracture stability and prevention of equinus contracture during his multiple procedures and treatment course.

3. Liberal skin incision length allowed for easy identification of anatomy, protection of neurovascular structures, and complete four-compartment fasciotomy.

4. Following fasciotomy and on return trips to the operating room, the surgeon must complete a thorough investigation of the muscle and soft tissues to ensure any nonviable tissue is debrided to prevent future infection.
5. If a two-incision technique is being utilized, it is imperative to draw out both incisions prior to making either incision to maintain a wide anterior soft tissue bridge. The previous belief of a required soft tissue bridge of at least 7 cm at the distal tibia has been questioned, but the practice of careful soft tissue handling and maintaining wide skin bridges whenever possible remain essential (Howard et al. 2006).
6. Care must be taken to identify compartment syndrome onset as delayed fasciotomy has a significant infection and amputation rate. The surgeon must also be aware and monitor for the potential systemic effects of compartment syndrome including rhabdomyolysis and renal impairment.

10 Cross-References

- [Tibial Shaft Fracture: Flexible Nails](#)

References and Suggested Reading

- Bae DS, Kadiyala RK, Waters PM (2001) Acute compartment syndrome in children: contemporary diagnosis, treatment and outcome. *J Pediatr Orthop* 21:680–688
- Ebraheim NA, Siddiqui S, Raberding C (2016) A single-incision fasciotomy for compartment syndrome of the lower leg. *J Orthop Trauma* 30(7):e252–e255
- Heckman MM, Whitesides ET, Grewe SR et al (1994) Compartment pressure in association with closed tibia fractures. *J Bone Surg* 76:1285–1292
- Howard JL, Agel J, Barei D, et al. (2006) Challenging the dogma of the 7-cm rule: a prospective study evaluating incision placement and wound healing for tibial platfond fractures. Presented at Orthopaedic Trauma Association annual meeting, Phoenix, 5–7 Oct 2006
- Kakar S, Firoozabadi R, McKean J et al (2007) Diastolic blood pressure in patients with tibia fractures under anaesthesia: implications for the diagnosis of compartment syndrome. *J Orthop Trauma* 21:99–103
- Maheshwari R, Taitsman LA, Barei DP (2008) Single-incision fasciotomy for compartmental syndrome of the leg in patients with diaphyseal tibial fractures. *J Orthop Trauma* 22(10):723–730
- Noonan KJ, McCarthy JJ (2010) Compartment Syndromes in the Pediatric Patient. *J Pediatr Orthop* 30:S96–S101

Tibial Shaft Fracture: Cast Treatment

Jeanne M. Franzone and Richard W. Kruse

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Abstract

A 14-year-old boy sustained a closed right tibial shaft fracture when tackled while kicking a field goal during a football game. The fracture was oblique and comminuted in the setting of open physes. He was treated with closed manipulation and long leg casting. The cast was wedged in the operating room to improve alignment. At 4 weeks postoperatively he was transitioned to a patellar tendon bearing fracture brace with touchdown weight bearing and physical therapy for gentle ankle and knee motion. Weight bearing was then progressed as the fracture continued to heal and the patellar tendon bearing fracture brace was cut down to a below-knee fracture brace. At 3 months postoperatively he was allowed to weight bear as tolerated without the fracture brace, and he was cleared to return to full activities 4 months postoperatively.

1 Brief Clinical History

A 14-year-old healthy boy presented with right lower leg deformity and pain after being tackled by three opponents while kicking a field goal during a football game. His skin and neurovascular status were intact. No other injuries were identified on the initial trauma survey. Radiographs demonstrated an oblique diaphyseal tibial fracture with comminution and a fibula fracture at the same level. He was initially stabilized in the emergency room with a long leg splint, and he was admitted for close observation. Closed reduction was performed under general anesthesia with long leg cast application. In the setting of a fracture with shortening or overlap, general anesthesia can provide muscle relaxation not available with conscious sedation in an emergency room setting. Immediate or provisional reduction in the emergency room is indicated in the setting of threatened perfusion, threatened skin, or to relieve pressure on an injured nerve.

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Fig. 1 Anteroposterior (a) and lateral (b) views of the right tibia and fibula demonstrating a diaphyseal oblique comminuted fracture

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Comminuted oblique tibial shaft fracture with a same-level fibular shaft fracture
2. Open phyeses

4 Treatment Strategy

Treatment options included closed versus open reduction with long leg casting or fixation with percutaneous pins, elastic intramedullary nails, a plate, an external fixator, or rigid intramedullary nailing. Given this patient's open phyeses, rigid intramedullary nailing should be avoided. Although there is a trend toward increasing use of intramedullary flexible nails in the pediatric and adolescent populations, this closed isolated injury is amenable



Fig. 2 Anteroposterior (a) and lateral (b) views of the right tibia and fibula following provisional long leg splinting in the emergency department

to closed reduction with cast immobilization. Fixation with flexible intramedullary nails may avoid the need for a long leg cast postoperatively but does incur an additional surgery for removal of hardware. A disadvantage to leaving flexible intramedullary nails in place in non-pathological growing bone is that removal becomes more difficult – particularly in a child with a significant amount of growth remaining in whom the nails can become buried and can also cause a stress riser. In the setting of closed reduction and cast immobilization, the cast may be changed to a short leg patella bearing cast or brace at 4 weeks with weight bearing immobilization until sufficient callus forms. Families opting for closed manipulation with cast immobilization must be informed regarding the potential need to convert to open reduction intraoperatively, if the fracture does not meet acceptable parameters and also regarding the potential need for cast wedging and re-manipulation in the early postoperative period.



Fig. 3 Anteroposterior (a) and lateral (b) radiographs of the right tibia and fibula following initial closed manipulation and long leg casting (prior to cast wedging)

5 Basic Principles

1. In addition to a full trauma evaluation, it is important to evaluate the knee and the ankle (the joint above and below the injury).
2. Acceptable parameters for tibial shaft fractures take into consideration the very limited capacity for remodeling of the tibial diaphysis, particularly in adolescents. Little or no more than 5° of angulation in the coronal or sagittal plane may be accepted. Although up to 10° of apex anterior angulation may be tolerated, very little apex posterior angulation can be tolerated as it forces the knee into extension during gait. At least 50% apposition is recommended for adolescents and less than 1 cm of shortening (Heinrich and Mooney 2010).
3. The initial cast may accept up to 20° of equinus to prevent recurvatum at the fracture site.
4. Cast wedging may be used intraoperatively or in the early postoperative period to fine-tune the fracture reduction.
5. The patient should be monitored closely following reduction and casting for signs of developing compartment syndrome.
6. Radiographs should be obtained on a weekly basis for the first 4 weeks postoperatively to monitor alignment of the fracture.



Fig. 4 Anteroposterior (a) and lateral (b) radiographs of the right tibia and fibula following closed reduction and long leg casting and cast wedging to correct a recurvatum deformity

6 Images During Treatment

See Figs. 3, 4, 5, and 6.

7 Technical Pearls

1. Muscle relaxation as a component of the general anesthesia is helpful in obtaining an acceptable closed reduction.
2. Initial fluoroscopic evaluation of the tibial shaft fracture determines the feasibility of the reduction as well as the reduction maneuver itself.
3. A cylinder cast may be initially applied while traction is applied on the foot. The foot is then manipulated to optimize fracture reduction and is then included in the cast. As stated above, up to 20° of equinus may be accepted to optimize fracture reduction and prevent recurvatum deformity.



Fig. 5 Anteroposterior (a) and lateral (b) radiographs of the right tibia and fibula 1 month following closed reduction and long leg casting. At this visit the patient was transitioned to a patellar tendon bearing brace and touch down weight bearing

4. Areas of bony prominence and the heel must be appropriately padded.
5. It is important for the long leg cast to include the full thigh up to the groin with a sufficient cuff of padding at the proximal aspect of the cast to prevent skin irritation.
6. When performing an open wedge technique, it is important to fill the gap in the cast material with soft padding in order to avoid wedge edema. When performing a closing wedge of the cast, it is important to avoid pinching the skin (AO Surgery Reference).

8 Outcome Clinical Photos and Radiographs

See Fig. 7.

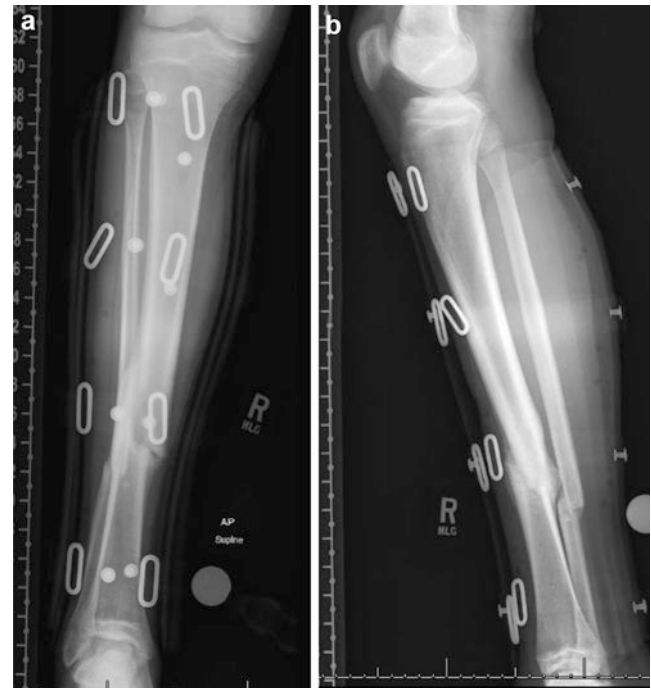


Fig. 6 Anteroposterior (a) and lateral (b) radiographs of the right tibia and fibula 3 months following closed reduction and long leg casting. At this visit the patient was permitted to weight bear as tolerated without the brace (no running, jumping, or high impact activities)

9 Avoiding and Managing Problems

1. Discuss ahead of time with the family the need for close radiographic follow-up and the potential need for re-manipulation or cast wedging as part of the treatment plan to avoid it being perceived as an unanticipated complication.
2. “There are no hypochondriacs in casts” – any complaints regarding discomfort in the cast must be taken seriously and investigated. Heel ulcers and other pressure sores can be serious complications of cast immobilization.
3. Patients requiring closed manipulation in the operating room should be elevated and clinically monitored. Bed rest of 24–48 h is often helpful in achieving elevation and patient comfort. In children, anxiety, increasing need for analgesics, and agitation (the “three A’s”) are the most sensitive signs of compartment syndrome (Bae et al. 2001).
4. The necessary arrangements need to be made regarding a wheelchair, transportation, and schooling. Proper arrangement of these social issues is an important part of the overall treatment plan.



Fig. 7 Anteroposterior (a) and lateral (b) radiographs of the right tibia and fibula 4 months following closed reduction and long leg casting. At this visit the patient was permitted to resume activities as tolerated

10 Cross-References

- [Tibial Shaft Fracture: Flexible Nails](#)
- [Tibial Shaft Fracture: Plating](#)

References and Suggested Reading

- AO Trauma Foundation (2016) AO surgery reference. <https://aotrauma.aofoundation.org/Structure/education/self-directed-learning/reference-materials/ao-surgery-reference/Pages/ao-surgery-reference.aspx>. Accessed 15 Jan 2017
- Bae DS, Kadiyala RK, Waters PM (2001) Acute compartment syndrome in children: contemporary diagnosis, treatment, and outcome. *J Pediatr Orthop* 21(5):680–688
- Heinrich SD, Mooney JF (2010) Fractures of the shaft of the tibia and fibula. In: Beaty JH, Kasser JR (eds) *Rockwood and Wilkins' fractures in children*, 7thedn. Lippincott Williams & Wilkins, Philadelphia
- Ho CA (2016) Tibia shaft fractures in adolescents: how and when can they be managed successfully with cast treatment? *J Pediatr Orthop* 36(4 Suppl 1):S15–S18

Osteochondral Fracture

Eric D. Shirley

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Abstract

A 16-year-old male presented after a twisting injury of the knee. Examination and imaging identified a loose osteochondral fracture. Surgery was indicated to remove and potentially reattach the loose body. The loose body was localized arthroscopically, and an arthrotomy was performed to achieve internal fixation. The fracture healed uneventfully, allowing return to full activities.

Conventional radiographs showed a loose body in the suprapatellar pouch. Magnetic resonance imaging (MRI) showed the donor site on the lateral femoral condyle. Surgery was indicated to remove and potentially reattach the fragment to restore the cartilaginous surface.

1 Brief Clinical History

A 16-year-old male presented with knee pain after a non-contact twisting injury. A traumatic hemarthrosis developed shortly after injury. The patient noted generalized pain without instability. Physical examination of the knee indicated no fixed contractures or focal tenderness and stable ligaments.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

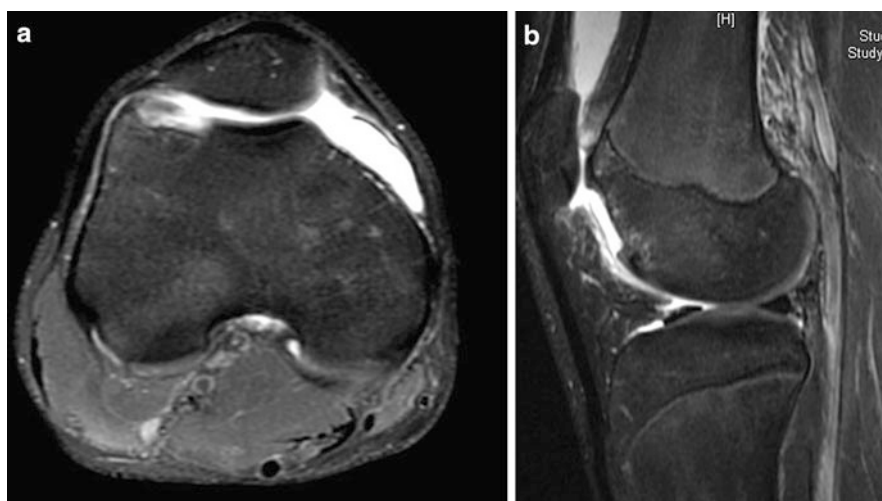
1. Traumatic hemarthrosis
2. Knee pain
3. Loose body secondary to osteochondral fracture with a >2-cm defect on the lateral femoral condyle

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Fig. 1 Anteroposterior (a) and lateral (b) radiographs after the injury. The loose body is only seen on the lateral view



Fig. 2 Axial proton density (a) and T-2 sagittal (b) MRI images show a defect (2.5×2 cm) on the lateral femoral condyle



4 Treatment Strategy

Treatment options included observation, physical therapy, loose body excision with microfracture or osteochondral autograft transplantation as needed, and osteochondral fragment fixation. Intervention with arthroscopy afforded the opportunity to restore the articular cartilage surface with native cartilage. Using 1.5-mm poly-96L/4D-lactide copolymer SmartNails (ConMedLinvote, Largo, FL) for fixation would allow

for healing without the need for subsequent hardware removal.

5 Basic Principles

1. A careful evaluation of the examination and imaging findings is required to ensure that any additional pathology, such as a medial patellofemoral ligament tear from a patellar dislocation, does not require treatment.

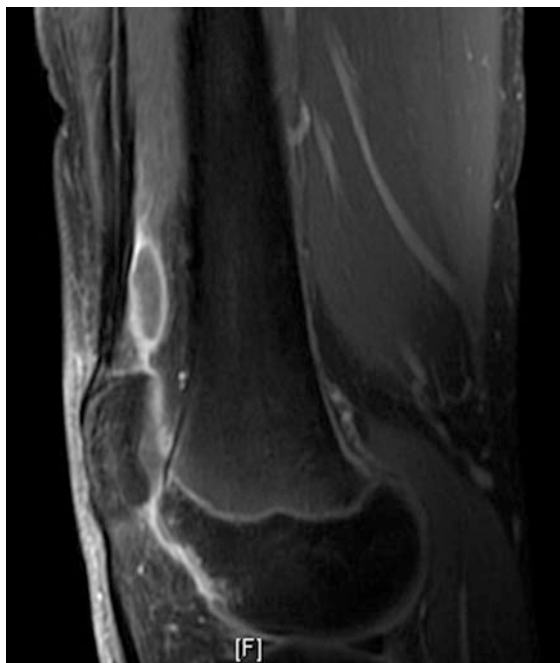


Fig. 3 This T2 sagittal MRI image demonstrates a loose body in the suprapatellar pouch

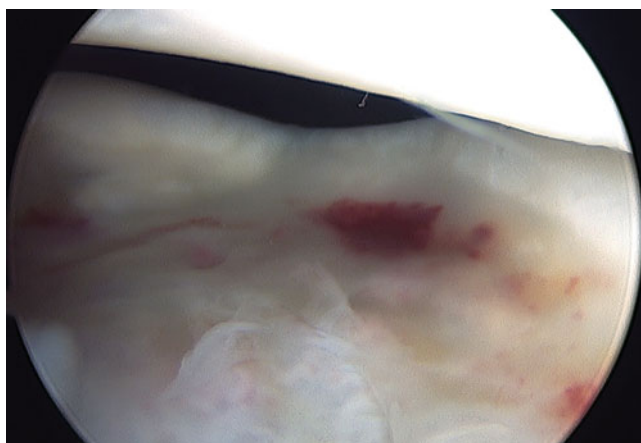


Fig. 4 The large defect on the lateral femoral condyle is visualized from the arthroscope to be engaging the patella

2. Preoperative MRI is advantageous because conventional radiographs may not visualize the loose body. In addition, MRI allows the clinician to determine whether the defect size and location in the weight bearing surface might benefit from fixation. When repair is an option, surgery should be scheduled as soon as possible because a longer time from injury may increase the chance of damaging or deforming the loose body, making repair not feasible.
3. The osteochondral fragment is inspected intraoperatively for cortical bone and healing potential.

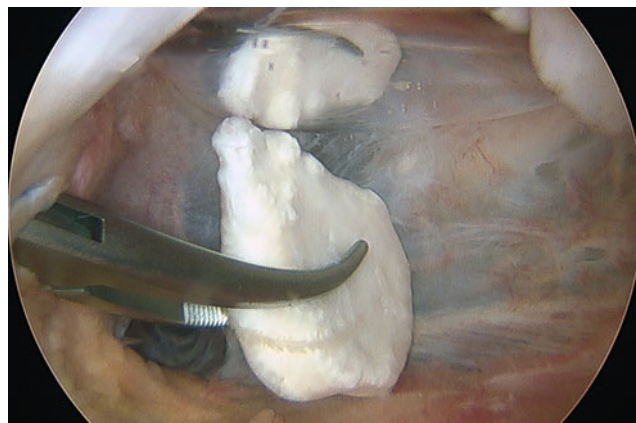


Fig. 5 Gentle arthroscopic removal of the loose body from an accessory portal

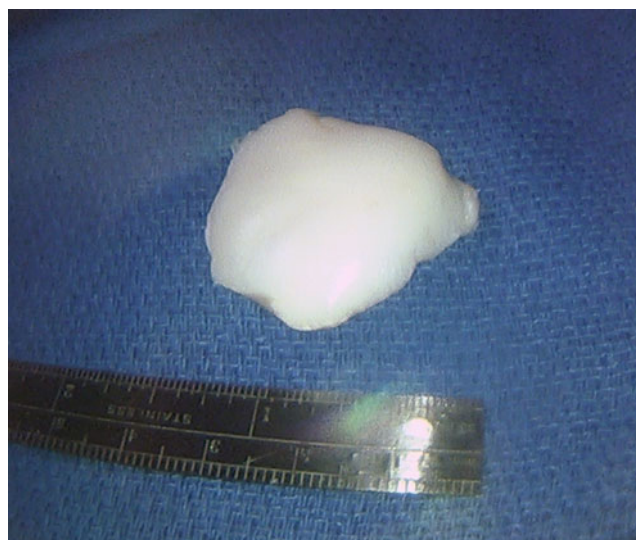


Fig. 6 The loose body is inspected to determine size and suitability for repair

4. The SmartNails are inserted just below the depth of the articular surface.

6 Images During Treatment

See Figs. 4, 5, 6, and 7.

7 Technical Pearls

1. The operating room is set up to allow space for both the arthroscopy tower and fluoroscopy in case assistance is needed to find the loose body.

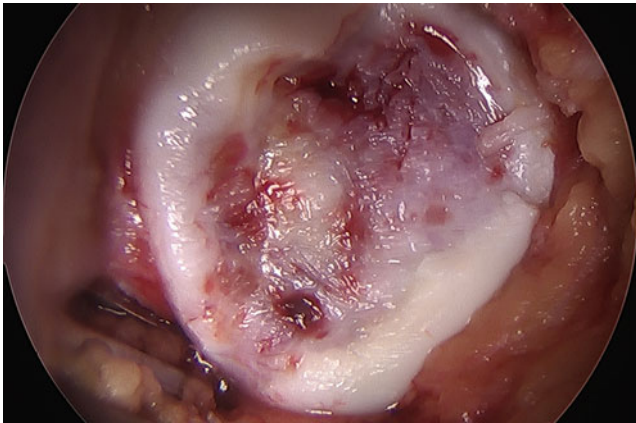


Fig. 7 The defect is exposed for preparation via a limited anterolateral arthrotomy

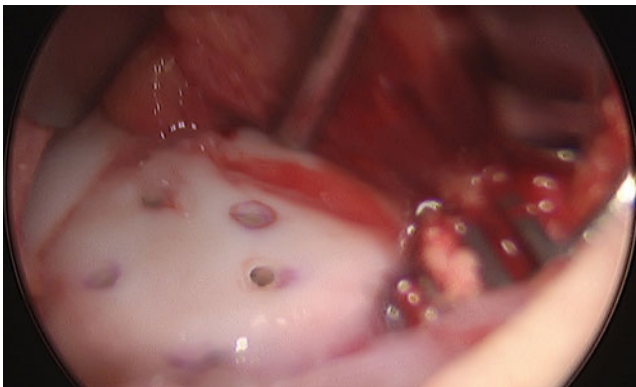
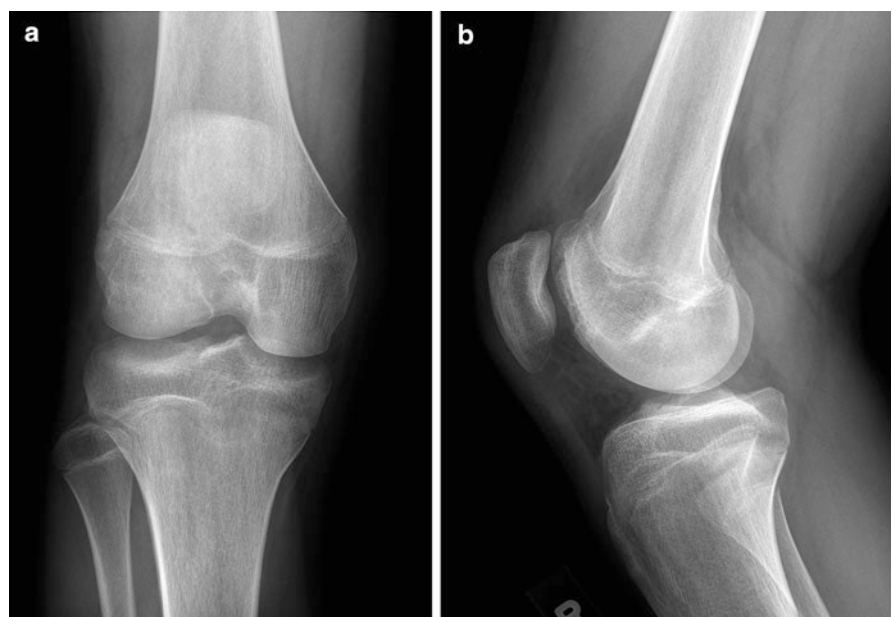


Fig. 8 Intraoperative photograph at completion of surgery demonstrates anatomic reduction and fixation of the osteochondral fragment. A smooth cartilaginous surface was restored, and bone grafting was not required

Fig. 9 The patient returned to full activity at 4 months after surgery. Anteroposterior (a) and lateral (b) knee radiographs obtained at that time demonstrate continued depression of the lateral femoral condyle, likely secondary to abnormal subchondral bone. The patient remained pain free at his 1-year follow-up



2. Using a separate inflow portal keeps the fluid in the arthroscope from pushing the loose body away. A spinal needle is inserted into the knee to hold the loose body as soon as it is identified.
3. The portal on the side of the donor site is extended sufficiently to allow removal. Care is taken to avoid damaging the loose body.
4. Once removed, the loose body is inspected further to determine if repair is feasible. An intact fragment of sufficient size from the weight bearing surface with a component of cortical bone is generally appropriate for repair.
5. The defect site is inspected to verify that it engages with the patella or tibia during range of motion. A 70° arthroscope may be needed to evaluate the patellofemoral joint.
6. A limited arthrotomy is made using the previous incision. A portion of the fat pad is excised if necessary. Wearing a headlight can be helpful when working through a small incision.
7. The donor site is prepared with a curette and irrigation. Bone graft from Gerdy's tubercle on the proximal tibia may be needed to achieve a smooth articular surface.
8. The loose body is then reduced into the donor site. Attention is required to ensure that the loose body is placed in the proper orientation. In addition, the edges of the loose body may have hypertrophied since the injury, requiring contouring to achieve an anatomic reduction.
9. Smooth Kirschner wires are used for provisional fixation.
10. Definitive fixation is achieved with 1.5- or 2.4-mm poly-96L/4D-lactide copolymer SmartNails 15–25 mm long. In skeletally immature patients, length must take into consideration the distance from the physis. SmartNails

are predrilled and then inserted using a tamp. The number of pins required (3–7) depends on lesion size. Other fixation options include cannulated screws, headless screws, and other bioabsorbable products. Advantages of the SmartNails include small size and avoiding the need for hardware removal.

11. Weight bearing is restricted for 6 weeks after surgery. Immobilization is usually not needed.
12. Physical therapy to restore motion and strength is begun at 6 weeks after surgery.

8 Outcome Clinical Photos and Radiographs

See Figs. 8 and 9.

9 Avoiding and Managing Problems

1. MRI may be obtained in patients with traumatic hemarthrosis and a suspected loose body to evaluate the opportunity to restore the articular surface with native cartilage.
2. Proceeding with surgery soon after injury decreases the risk of loose body deformation and hypertrophy.
3. Care is made to restore the proper orientation of the osteochondral fragment into the donor site.
4. Postoperative pain requires a follow-up MRI to evaluate the cartilaginous surface.

Editors' Tips and Pearls

The differential diagnosis of traumatic hemarthrosis of the knee in young patients includes intra-articular fractures, anterior cruciate ligament tears, meniscal tears, patellar dislocations, and osteochondral fractures. Articular cartilage lesions in young patients are challenging, and large defects will lead

to early arthritis. Because of the limited ability of articular cartilage to heal, young patients like the one presented in this case should have an attempt at reduction and fixation of the osteochondral fragment. Some reports (see Walsh et al. 2008) of healing of cartilage fragments that do not have much bone attached have also been noted – in very young patients consideration should be given to absorbable pin fixation of large chondral fragments.

10 Cross-References

► Patellar Sleeve Fracture

References and Suggested Readings

- Gkiokas A, Morassi LG, Kohl S, Zampakides C, Megremis P, Evangelopoulos DS (2012) Bioabsorbable pins for treatment of osteochondral fractures of the knee after acute patella dislocation in children and young adolescents. *Adv Orthop* 2012:249687. <https://doi.org/10.1155/2012/249687>
- Hoshino CM, Thomas BM (2010) Late repair of an osteochondral fracture of the patella. *Orthopedics* 3(4). <https://doi.org/10.3928/01477447-20100225-25>
- Kramer DE, Pace JL (2012) Acute traumatic and sports-related osteochondral injury of the pediatric knee. *Orthop Clin North Am* 43(2):227–236, vi. <https://doi.org/10.1016/j.ocl.2012.02.001>
- Kumahashi N, Kuwata S, Imade S, Kono M, Takuwa H, Uchio Y (2012) Fixation of osteochondral fractures of the patella using autologous bone screws when reconstructing the medial patellofemoral ligament after recurrent patellar dislocation: report of two cases. *J Orthop Sci.* <https://doi.org/10.1007/s00776-012-0285-x>
- Lee BJ, Christino MA, Daniels AH, Hulstyn MJ, Eberson CP (2013) Adolescent patellar osteochondral fracture following patellar dislocation. *Knee Surg Sports Traumatol Arthrosc* 21(8):1856–1861. <https://doi.org/10.1007/s00167-012-2179-z>
- Walsh BSJ, Boyle MJ, Morganti V (2008) Large osteochondral fractures of the lateral femoral condyle in the adolescent: outcome of bioabsorbable pin fixation. *J Bone Joint Surg Am* 90(7):1473–1478. <https://doi.org/10.2106/JBJS.G.00595>

Part VI

Lower Extremity: Foot and Ankle

Distal Tibial Metaphyseal Fracture: Plating

Oussama Abousamra

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Abstract

A 14-year-old boy sustained a crushing injury to his left foot. The injury was isolated to the left lower extremity. Neurovascular examination did not show any abnormalities. Clinical examination and imaging revealed a left closed distal tibial and fibular fracture. The tibia fracture was comminuted, oblique, and displaced with a recurvatum deformity. Since this type of fracture is unstable, surgical fixation was indicated. In this particular case, the decision was made to proceed with open reduction and plating of both the distal tibial and the fibular fractures.

Although tibial fractures are common in children, the incidence of distal metaphyseal fractures is not known. Options to surgically address distal tibial fractures include internal fixation or external fixation. Different internal fixation options are available to address distal tibial fractures such as an interlocking intramedullary nails or plate and screws. The distal tibial plate can be placed on the medial

or lateral side of the tibia with advantages and disadvantages for each method. Care should be taken not to injure the open physes in the distal tibia and fibula while implants are placed.

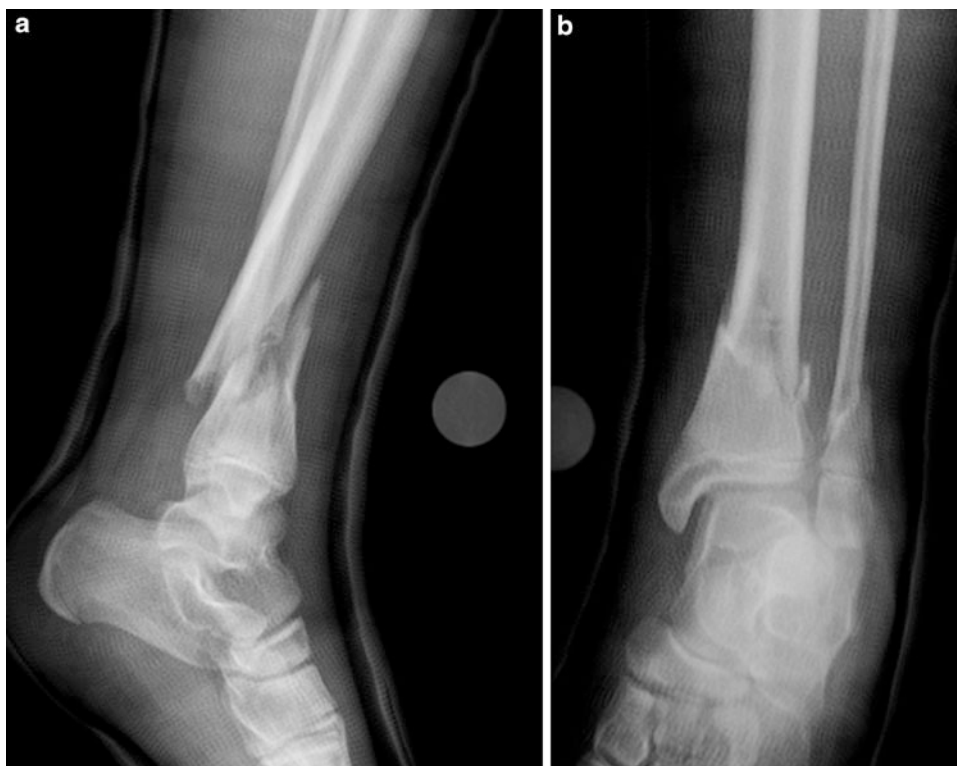
After the procedure was completed, the leg was placed in a well-padded short leg splint. Pain control, 24 hours of antibiotics, and strict leg elevation were recommended. The patient was discharged home in good condition the next day with instructions of non-weight-bearing. Regular outpatient follow-up visits were arranged. After 6 weeks, radiographs showed satisfactory healing and weight-bearing as tolerated was allowed. The fracture healed uneventfully, and the last follow-up was at 6 months after surgery with full ankle range of motion.

1 Brief Clinical History

A 14-year-old boy presented with pain and swelling of his left foot after sustaining a crush injury by a motor vehicle. Clinical examination revealed a swollen foot with pain and tenderness. The left lower extremity was neurovascularly

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Fig. 1 (a) Lateral radiograph of the left leg showing a comminuted oblique distal tibial and fibular fractures. (b) Anteroposterior radiograph of the left leg showing a comminuted oblique distal tibial and fibular fractures



intact. No symptoms or signs of compartment syndrome were noted. The fracture was closed with no open skin wounds. The injury was an isolated extremity injury and the patient did not have other complaints. Radiographic examination showed fractures of the left distal tibia and fibula.

2 Preoperative Clinical Photos and Radiographs

(Fig. 1).

3 Preoperative Problem List

1. Lower leg and foot pain and tenderness.
2. Foot swelling.
3. Inability to bear weight.
4. Distal tibial oblique fracture and distal fibular oblique fracture.

4 Treatment Strategy

Multiple management options are available to approach distal tibial fractures. Conservative management includes closed reduction with casting. However, since the fracture in this case was unstable, surgical fixation was indicated to maintain

reduction and alignment. Different options for fixation implants are also available. External fixation allows for rigid fixation with the advantage of reducing the fracture in a closed manner. Disadvantages include the potential pin track infection and the need to wear the external fixator for a few months. Internal fixation options include rigid interlocking intramedullary nail or plate and screws. If a nail is used, open reduction may not be necessary. The procedure involves less soft tissue dissection than a plating. However, controlling the distal fragment and maintaining alignment with good fixation are difficult. Open reduction with plating has the advantage of being able to control the fracture fragments and obtain an anatomic reduction. Disadvantages of plating include the extensive soft tissue dissection needed to place the implant. Minimally invasive plating with percutaneous screw insertion has been reported. Although it is an attractive technique, obtaining and maintaining anatomic reduction are difficult.

In this particular case, the decision was made to proceed with open reduction and plating of both the distal tibial and the fibular fractures. Locking plates were used with 3.5 mm screws in the distal tibia and 2.7 mm screws in the distal fibula. The decision whether to place the distal tibial plate medially or laterally was made based on the surgeon's preference. No difference in outcomes has been reported between these two techniques. While anterolateral approach might be technically demanding and require a long incision, medial plating can be associated with soft tissue compromise and symptomatic implants that need subsequent removal.

Fig. 2 (a–d) Intraoperative fluoroscopy of fracture reduction and internal fixation of left tibia and fibula



Postoperative care includes placing the leg into a short leg splint with strict leg elevation. The patient is admitted for overnight observation. After discharge, regular follow-up is arranged. On the first postoperative follow-up at 2 weeks after surgery, the splint is removed, and incisions are checked. The leg is then placed in a removable orthosis to encourage free non-weight-bearing ankle range of motion. At 6 weeks postoperatively, weight-bearing as tolerated is allowed. Physical therapy may be needed to help regain full ankle range of motion. Follow-up is recommended until the fracture is fully healed radiographically.

5 Basic Principles

1. As in any injury to an extremity, general evaluation of the patient is necessary to detect any associated injury.
2. Neurovascular examination is essential in the primary assessment of the involved extremity.
3. The knee and ankle joints are evaluated clinically and radiographically for any injury.
4. Soft tissue swelling, abrasions, blisters, and other soft tissue compromise need to be evaluated carefully and documented to determine if the extremity's condition is

Fig. 3 (a and b) Immediate postoperative anteroposterior and lateral radiograph of the left tibia and fibula

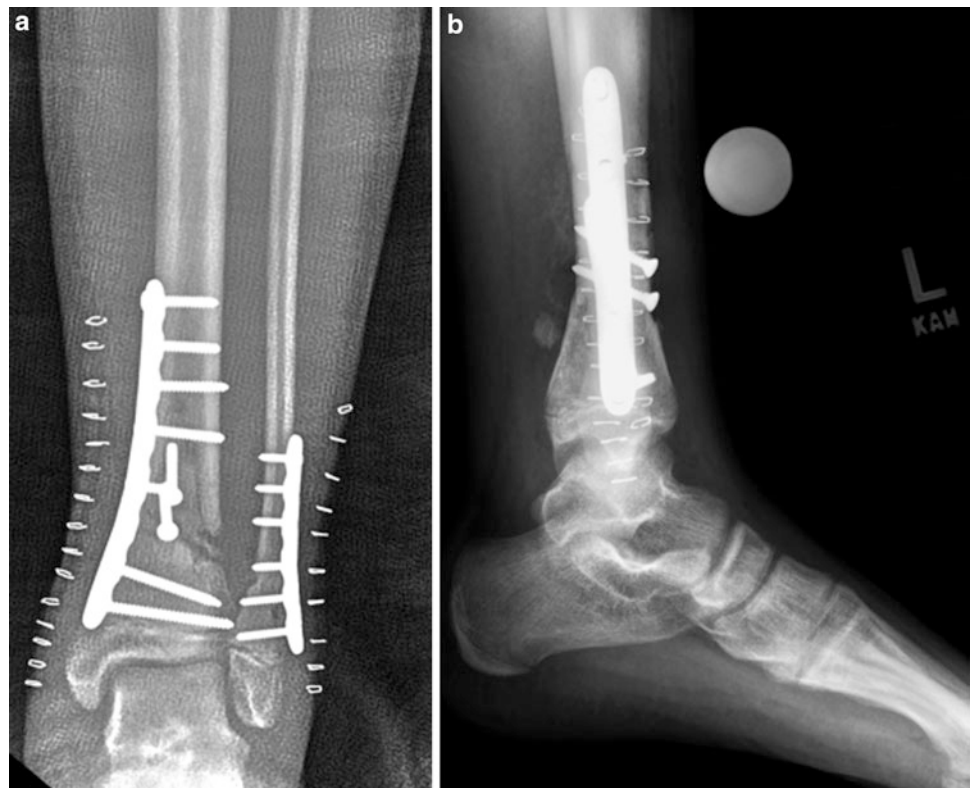


Fig. 4 (a and b) Anteroposterior and lateral radiographs of the left tibia and fibula, 6 months after surgery



favorable to proceed with surgery. Otherwise, the surgery could be delayed to avoid soft tissue complications.

5. Temporary stabilization with a splint is performed for comfort and pain control during the preoperative assessment.

6 Technical Pearls

1. The entire lower extremity is prepped and draped with the patient in the supine position.
2. A tourniquet (sterile or non-sterile) is used on the ipsilateral upper thigh to minimize blood loss and facilitate the approach.
3. A longitudinal incision is made over the lateral aspect of the fibula and carried down to the fracture, protecting the sural nerve posteriorly.
4. A subperiosteal dissection is performed to expose the fracture. Periosteal dissection is limited to the edges of the fracture and should be minimized to avoid any compromise to the vascular supply.
5. Distraction helps with fracture reduction, and the fracture is stabilized using 2.7 locking plate.
6. A longitudinal incision is made over the anterior aspect of the distal tibia and carried down to the fracture site.
7. Subcutaneous soft tissue should be dissected carefully keeping full-thickness flaps to avoid compromising the vascular supply.
8. A subperiosteal dissection is made to expose the fracture. Again, the periosteal dissection should be kept to a minimum around the fracture edges.
9. Reduction is obtained with manipulation and distraction. Individual lag screws might be helpful in reducing individual fragments as shown in Fig. 2.
10. Fixation is obtained with a 3.5 mm locking plate.
11. The wound is irrigated and closed in layers. Closure needs to be completed carefully by ensuring soft tissue coverage over the implant and by avoiding skin tension.
12. A short leg cast is applied over sterile dressings.
13. The patient is admitted for 24 h with pain control and antibiotics. Strict leg elevation is recommended.

7 Outcome Clinical Photos and Radiographs

(Figs. 3 and 4)

8 Avoiding and Managing Problems

1. Careful dissection, maintaining an adequate soft tissue layer, helps with postoperative wound care.
2. Restoring the full length of the fibula and tibia is essential especially in comminuted fractures.
3. Lag screws can help with reduction of individual bony fragments.
4. Careful soft tissue closure is important to obtain an adequate coverage over the implant, especially in medially placed plates.

9 Cross-References

- [Distal Tibial Shaft Fracture with Metaphyseal Extension: External Fixation](#)

References and Suggested Reading

- Manninen MJ, Lindahl J, Kankare J, Hirvensalo E (2007) Lateral approach for fixation of the fractures of the distal tibia. Outcome of 20 patients. Technical note. *Arch Orthop Trauma Surg* 127(5):349–353
- Masquijo JJ (2014) Percutaneous plating of distal tibial fractures in children and adolescents. *J Pediatr Orthop B* 23(3):207–211
- Sathiyakumar V et al (2014) Distal tibia fractures and medial plating: factors influencing re-operation. *Int Orthop* 38(7):1483–1488
- Vaianti E, Schiavi P, Ceccarelli F, Pogliacomi F (2018) Treatment of distal tibial fractures: prospective comparative study evaluating two surgical procedures with investigation for predictive factors of unfavourable outcome. *Int Orthop*. [Epub ahead of print]
- Yenna ZC, Bhadra AK, Ojike NI, ShahulHameed A, Burden RL, Voor MJ, Roberts CS (2011) Anterolateral and medial locking plate stiffness in distal tibial fracture model. *Foot Ankle Int* 32(6):630–637

Distal Tibial Shaft Fracture with Metaphyseal Extension: External Fixation

Oussama Abousamra

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Abstract

A 13-year-old male presented to the emergency department with head trauma and right lower leg injury after being struck by a motor vehicle. Examination and imaging identified an open right, unstable, spiral distal third tibial fracture in a skeletally immature male. Surgery was indicated to irrigate the wound and to reduce and stabilize the fracture. An external fixator was applied to the right lower leg to stabilize the fracture and facilitate wound care. The fracture healed uneventfully in 3 months.

shortened leg in valgus malalignment. The foot was externally rotated with good perfusion. The patient did not have any other associated musculoskeletal injuries, except moderate concussion. Radiographic examination showed a distal third tibial fracture, shortened in valgus with a minimally displaced fibular fracture.

1 Brief Clinical History

A 13-year-old male presented with pain in his right leg after he was struck by a motor vehicle. Clinical examination revealed a 2 × 1 cm wound, Gustilo-Anderson type II, and

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

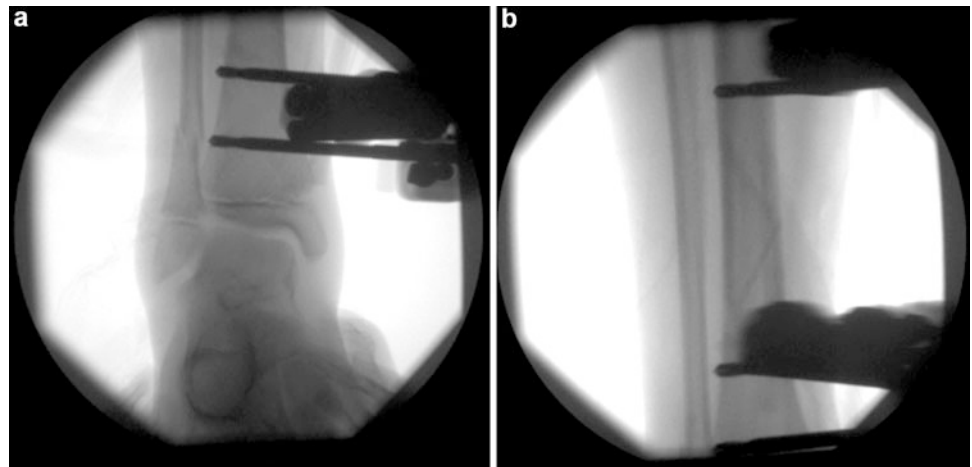
1. Distal tibial spiral fracture and distal fibular oblique fracture
2. Skin injury and open fracture

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Fig. 1 (a) Anteroposterior radiograph of the right leg showing a spiral fracture in the distal tibia and an oblique fracture of the distal fibula. (b) Lateral radiograph of the right leg showing a spiral fracture in the distal tibia extending into the metaphysis and an oblique fracture of the distal fibula



Fig. 2 (a, b) AP and lateral intraoperative fluoroscopy views of tibia and fibula



4 Treatment Strategy

The child received antibiotics in the emergency room on arrival. Antibiotics were given as soon as possible to decrease risk for infection. Tetanus status was assessed and noted to be up to date. A careful neurovascular exam was performed, including evaluation for compartment syndrome. The wound was assessed and irrigated. He was taken to the operating room for further irrigation and

debridement and stabilization of the open fracture. There is evidence in the literature that the infection rate is not significantly increased if debridement occurs >6 h from injury, although expedient antibiotic administration and debridement are recommended (Skaggs et al. 2000). According to Rodriguez, cephazolin (or clindamycin if allergic) should be administered in both grade I and II open fractures (Rodriguez et al. 2014).

The fracture was assessed further under fluoroscopic guidance. The tibial fracture extended into the metaphysis but not

Fig. 3 (a, b) Immediate postoperative anteroposterior radiograph of the right tibia

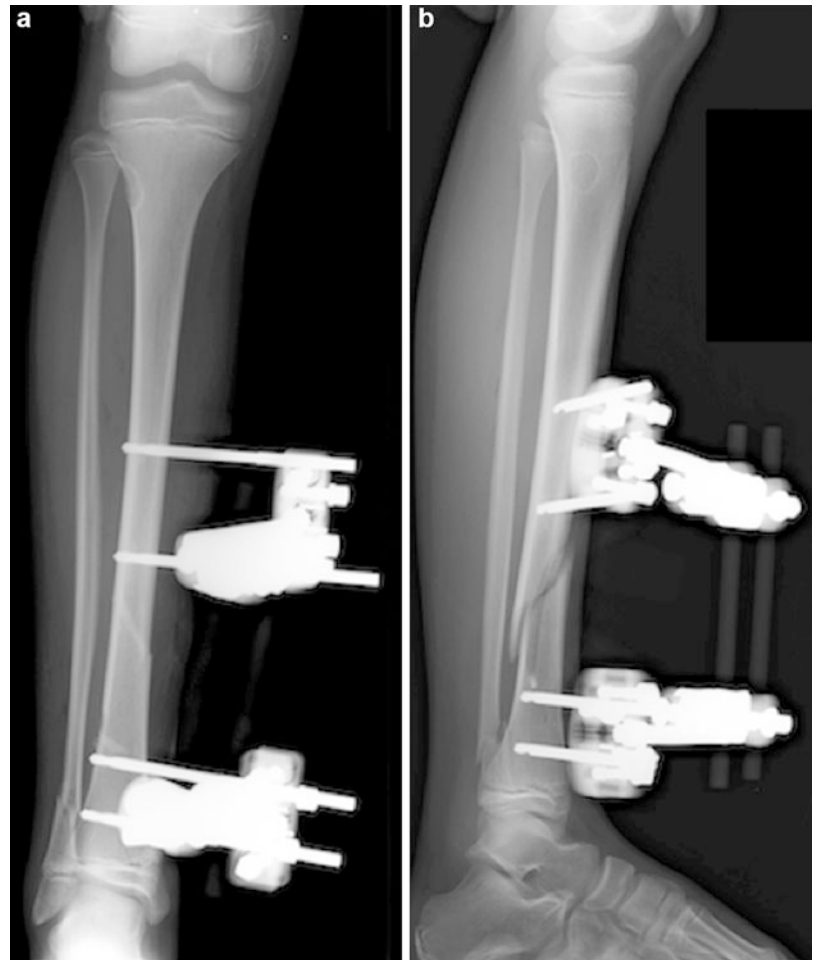


Fig. 4 (a, b) Anteroposterior radiographs of the right tibia, 3 months after surgery



distally into the physis. A CT scan can also be ordered to further assess the extent of the fracture if necessary preoperatively.

External fixation is one possible option for fixation of these distal tibial and fibular fractures. Because of the history of head trauma and open fracture, a unilateral external fixator

was applied to minimize operative time. Other options for fixation after assessment of the wound include windowed cast, flexible nails, thin wire external fixation, or hexapod external fixator with wires or half pins or a plate. In this case a simple, unilateral external fixator, with four 5 mm pins, was applied. The external fixator was used for definitive fixation and was removed 3 months later. No pin tract infections occurred.

5 Basic Principles

1. Primary assessment and cardiorespiratory stabilization remain the first priority in the management of patients with potential multiple injuries. Primary, secondary, and tertiary evaluations should be performed. Monitor for compartment syndrome.
2. Antibiotics should be administered expeditiously in open fractures. Irrigation and debridement should also occur in a timely fashion. Update tetanus if necessary.
3. After ruling out other system injuries, other skeletal injuries, or neurovascular compromise, clinical and radiographic examination is necessary to determine the fracture pattern.
4. The knee and ankle joints are examined radiographically to rule out any possible injury.
5. Temporary stabilization, using a splint, is important until definitive fixation is performed.
6. If using an external fixator for definitive treatment, use techniques to minimize thermal injury (sharp drill bits, avoid unicortical pins, cool saline on drill bit during drilling) for half-pin insertion.
7. Following half-pin insertion, reduction is performed under fluoroscopic control, and the external fixator is tightened once adequate reduction is achieved.

Images during treatment (Fig. 2)

6 Technical Pearls

1. A radiolucent table is used to allow fracture reduction under fluoroscopic control.
2. The wound is adequately irrigated with saline and foreign material removed. Enlarge the laceration as needed to fully appreciate soft tissue damage (zone of injury) which is often more significant than the skin laceration. Any nonviable soft or hard tissue should be debrided in most cases.
3. A radiopaque instrument is used to locate appropriate placement of the half pins on the medial face of the tibia.

4. The planned incision is marked on the skin. A stab incision is made and a hemostat is used to dissect the soft tissue down to the bone. The pin site is predrilled minimizing heat with insertion. Insert half pins by hand or on ream to further minimize heat production and pin tract complications.
5. The most distal pin is inserted first. The fixator is secured distally and then, the proximal pins are inserted.
6. The central part of the fixator is loosened, the fracture is reduced, and the fixator is tightened.
7. Wounds are washed and closed if possible. If not possible, consider negative pressure dressing.
8. Weight-bearing is restricted based on stability of external fixator.
9. In this case a monolateral external fixator was applied, but a hexapod fixator could also be used.

7 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

8 Avoiding and Managing Problems

1. Neurovascular examination of the involved extremity is important in detecting any possible accompanied injury.
2. Proper placement of the pins helps maintain fixation. Creating a stable frame enhances fracture healing and comfort level.
3. Pin site infection is very common. Pin site care helps minimize frame complications and comfort level. Hydroxyapatite-coated pins may be used to create a more biologic seal.

9 Cross-Reference

► [Distal Tibial Metaphyseal Fracture: Plating](#)

Suggested Reading

- Gordon JE, Kelly-Hahn J, Carpenter CJ et al (2000) Pin site care during external fixation in children: results of a nihilistic approach. *J Pediatr Orthop* 20(2):163–165
- Iobst CA (2016) Hexapod external fixation of tibia fractures in children. *J Pediatr Orthop* 36((4)S1):24–28
- Laine JC, Cherkashin A, Samchukov M et al (2016) The management of soft tissue and bone loss in type IIIB and IIIC pediatric open tibia fractures. *J Pediatr Orthop* 36(5):453–458

- Rodriguez L, Jung HS, Goulet JA, Cicalo A, Machado-Aranda DA, Napolitano LM (2014) Evidence-based protocol for prophylactic antibiotics in open fractures: improved antibiotic stewardship with no increase in infection rates. *J Trauma Acute Care Surg* 77(3):400–407
- Schranz PJ, Gultekin C, Colton CL (1992) External fixation of fractures in children. *Injury* 23(2):80–82
- Shore BJ, DeMauro JP, Spence DD et al (2015) Uniplanar versus Taylor spatial frame external fixation for pediatric diaphyseal tibial fractures: a comparison of cost and complications. *J Pediatr Orthop* 36(8):821–828
- Skaggs DL, Kantz SM, Kay RM, Tolo VT (2000) Effect of delay of surgical treatment on rate of infection in open fractures in children. *J Pediatr Orthop* 20(1):19

Salter-Harris II Distal Tibia and Fibula Fractures

Lucio Ricieri Perotti and L. Reid Nichols

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Abstract

An 8-year-old boy presented to the emergency department after he was struck by a car in a parking lot. The boy sustained closed right distal tibia and fibula fractures. A closed reduction was performed in the emergency department under conscious sedation. However, after the reduction attempt, there was continued displacement, angulation, and lateral physeal widening of the distal tibia. An open reduction and internal fixation was performed. The periosteum was entrapped in the medial physis. Once removed, an anatomic reduction was achieved. The ankle was

immobilized for 6 weeks in a cast and healed without growth disturbance.

1 Brief Clinical History

An 8-year-old boy presented to the emergency department after he was struck by a car in a parking lot. The boy had immediate right ankle and leg pain and a valgus deformity of the lower extremity. He was neurovascularly intact in the right lower extremity. Radiographs showed a displaced distal tibia Salter-Harris type II fracture with associated distal fibular fracture (Figs. 1 and 2). A closed reduction was attempted in the emergency department under sedation followed by cast immobilization. The tibia and fibula fractures were malreduced and showed displacement, valgus angulation, and lateral physeal widening in the distal tibia (Figs. 3 and 4). Using fluoroscopy an open reduction was performed with a careful dissection through the subcutaneous tissues to the periosteum. Neurovascular structure were identified and protected. The periosteum was brought out of

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Fig. 1 (a) Anteroposterior, (b) mortise or internal oblique view, and (c) lateral ankle radiographs show a displaced distal tibia Salter-Harris type II and distal fibular fractures

the physis with gentle manipulation. Reduction was then achieved (Fig. 5a). The fracture was stabilized with two smooth Kirschner wires (K-wires) placed through the medial malleolus across the physis and into the distal tibial metaphysis in a bicortical configuration (Fig. 5b, c). Anteroposterior and lateral views demonstrated an acceptable position of the K-wires and anatomical reduction of the fracture. Gentle varus and valgus stress of the fracture confirmed stability and restoration of the alignment of the distal tibia epiphysis with the metaphysis with complete reduction. Radiographs were obtained after a long leg cast was applied and confirmed anatomical reduction (Fig. 6).

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Acute physeal displaced fracture in the left distal tibia including Salter-Harris type II fracture, displaced distal fibula fracture
2. Swelling of the left leg and ankle with concern of impending compartment syndrome

3. Physeal growth remaining in the left distal tibia and possible premature physeal closure with growth arrest leading to angular ankle deformity and lower limb discrepancy

4 Treatment Strategy

It is important to understand the pattern and characteristics of distal tibia fractures in children using Dias-Tachdjian classification system (Dias and Tachdjian 1978). This case was classified as a pronation-eversion-external rotation (Fig. 1). The first term refers to the position of the foot at time of injury. The second term is related to the direction of the deforming force, with grades of injury described in increasing severity (Herring 2013). After an unsuccessful attempt of closed reduction with radiographs showing a widening (>3 mm) of distal tibia physis and persistent angulation, open reduction for removal of interposed periosteum in the physis was performed. After removal of the soft tissue, an anatomic reduction was achieved. Then a percutaneous pinning with two K-wires was performed to maintain reduction during healing (Figs. 5 and 6). A non-weight-bearing long leg cast was applied for the first 3 weeks postreduction. The cast was changed to a short leg cast for a total of 6 weeks of immobilization. After removal of the short leg cast, the boy started physical therapy and progressed weight-bearing as he could tolerate.

Fig. 2 (a) Anteroposterior and (b) lateral radiographs of right leg show no other associated fractures



5 Basic Principles

The surgeon must recognize the mechanism and features of distal tibial fracture. The Dias-Tachdjian classification system allows a better understanding of the mechanism of the fracture and guides the surgeon to achieve anatomical reduction. Fractures with >3 mm of physal widening after closed reduction may be more likely to develop premature physal closure. Many experts now are concerned more about the quality of reduction, especially normal alignment of the mortise, in these fractures (Russo et al. 2013). The inability to achieve an anatomical reduction is often caused by interposed soft tissue, particularly periosteum (Barmada et al. 2003). Before taking the patient to OR, the surgeon must know if there are any possible blocks to achieving an anatomic closed reduction. Then open reduction and internal reduction is always remains a possibility. After reduction, displaced distal tibia Salter-Harris type II can be treated with a long leg non-weight-bearing cast for the first 3–4 weeks,

followed by short leg cast for the next 2–3 weeks. Non-displaced distal tibia Salter-Harris type II fractures can be treated in either a long leg or short leg non-weight-bearing casts for 3–4 weeks. They can be transitioned to short leg non-weight-bearing cast, with gradual return to weight-bearing, for a total of 4–6 weeks of immobilization.

6 Images During Treatment

See Figs. 3, 4, 5, and 6.

7 Technical Pearls

1. The Dias-Tachdjian classification (Dias and Tachdjian 1978) is a descriptive classification and provides understanding of fracture characteristics and how to perform the reduction maneuver. Most distal tibia fractures can be

Fig. 3 (a) Anteroposterior and (b) lateral right ankle images with fluoroscopy after closed reduction attempt in the emergency department



Fig. 4 (a) Anteroposterior (AP), (b) mortise, and (c) lateral right ankle radiographs after closed reduction in ED. AP and mortise show a nonanatomical reduction of fracture with valgus angulation

and physeal widening of distal tibia. Also, lateral metaphyseal fragment (Thurston-Holland fragment) in distal tibia was not reduced

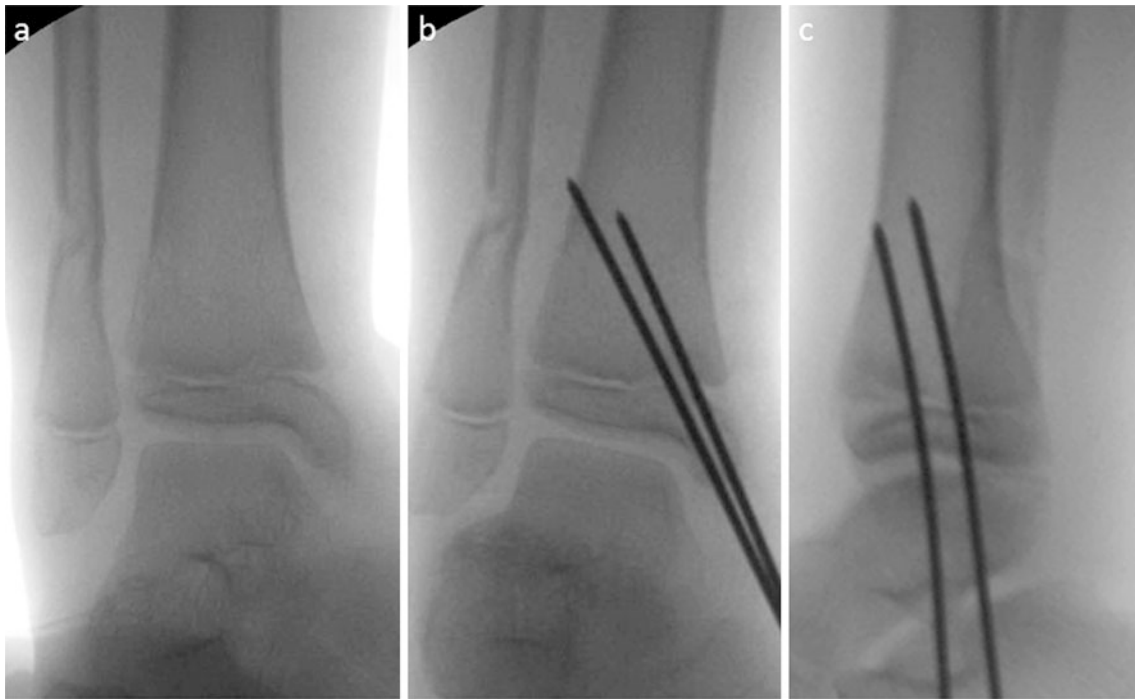


Fig. 5 Intraoperative fluoroscopy shows an anatomical reduction with no widening of distal tibia physis in (a) AP view. Also, (b) AP shows a good position of two K-wires and (c) lateral view confirm two K-wires in parallel shape

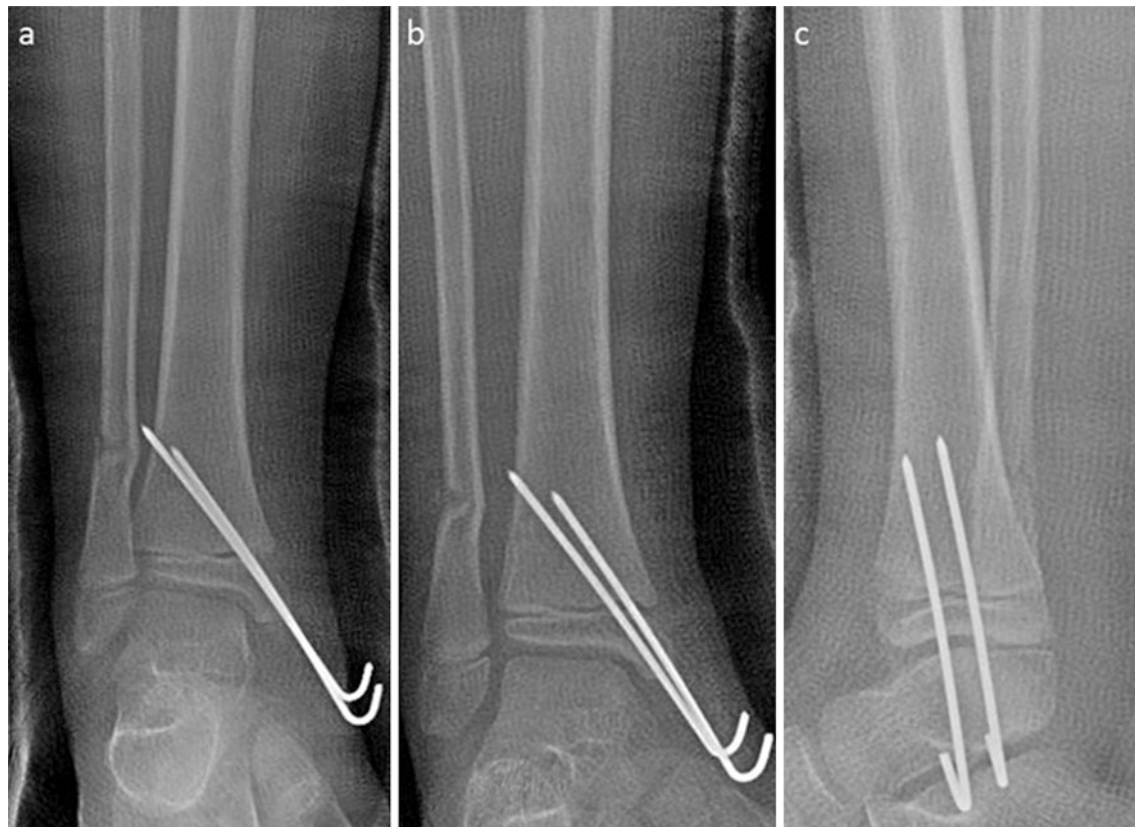


Fig. 6 (a) AP, (b) mortise, and (c) lateral radiographs of right ankle show an anatomical reduction of distal tibia and fibula fractures



Fig. 7 (a) AP, (b) mortise, and (c) lateral radiographic views of the ankle 6 weeks after the procedure. At this point both K-wires were removed



Fig. 8 AP, (b) mortise, and (c) lateral weight-bearing radiographs of the right ankle show a well-healed distal tibia and fibula fractures with no signs of premature physeal closure and no angular deformity of the ankle. Growth slowdown lines show resumption of normal physeal growth

treated with closed reduction followed by external immobilization (Herring 2013).

2. Nondisplaced Salter-Harris type II can be immobilized in a short leg cast for 4 weeks, followed by weight-bearing cast or walking boot for a total of 6 weeks of immobilization (Blackburn et al. 2012).

8 Outcome Clinical Photos and Radiographs

See Figs. 7 and 8.

9 Avoiding and Managing Problems

1. There is a controversy as to what represents an acceptable reduction for displaced distal tibia Salter-Harris type II (Blackburn et al. 2012).
2. One series showed premature physeal closure can occur in 60% of distal tibia Salter-Harris type I and II fractures with >3 mm of physeal widening and in 17% with <3 mm of physeal widening after reduction and recommended surgery for physeal gaps to decrease the incidence of growth disturbance (Barmada et al. 2003), but a later series by the same group showed that surgery to remove interposed periosteum did not lower the incidence of premature closure of the physis (Russo et al. 2013).

3. Physeal widening after closed reduction attempt can be an indication of interposed soft tissue. Removal of an interposed periosteum to reduce the physeal gap allows for restoration of alignment but does not appear to decrease the rate of premature physeal closure (Russo et al. 2013).

10 Cross-References

- [Salter-Harris III Distal Tibia Fracture](#)

References and Suggested Reading

- Barmada A, Gaynor T, Mubarak SJ (2003) Premature physeal closure following distal tibia physeal fractures: a new radiographic predictor. *J Pediatr Orthop* 23(6):733–739
- Blackburn EW, Aronsson DD, Rubright JH, Lisle JW (2012) Ankle fractures in children. *J Bone Joint Surg. American* Volume 94(13): 1234–1244
- Dias LS, Tachdjian MO (1978) Physeal injuries of the ankle in children: classification. *Clin Orthop Relat Res* 136:230–233
- Herring JA (2013) Tachdjian's pediatric orthopaedics: from the Texas Scottish Rite Hospital for Children. Elsevier Health Sciences, Philadelphia
- Russo F, Moor MA, Mubarak SJ, Pennock AT (2013) Salter-Harris II fractures of the distal tibia: does surgical management reduce the risk of premature physeal closure? *J Pediatr Orthop* 33:524–529

Salter-Harris III Distal Tibia Fracture

Lucio Ricieri Perotti and L. Reid Nichols

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Abstract

A 13-year-old boy sustained a left ankle trauma while playing soccer. He was taken to the emergency department where he was diagnosed with a Salter-Harris type III fracture of the medial malleolus (medial corner) of the left distal tibia. He was splinted initially in the emergency department. The ankle was significantly swollen. He returned 4 days later to routine follow-up and to have a computed tomography (CT) scan. The CT scan showed displacement of 5 mm at the articular surface. This case shows the importance of performing a clinical and radiographic routine surveillance of Salter Harris type III fracture. A CT scan helps to evaluate displacement of the articular surface

in order to decrease the risk of post-traumatic arthritis or in younger patients' growth arrest with angular deformities and/or lower limb length discrepancy.

1 Brief Clinical History

A 13-year-old boy reported that while playing soccer he suddenly felt pain after twisting his ankle. According to his description, he sustained a supination-inversion injury. His left ankle and foot were significantly swollen. After a radiographic evaluation with three views of his left ankle, anteroposterior, 20° internal oblique or mortise, and lateral, he was diagnosed with a distal tibia Salter-Harris type III fracture. Neurovascular exam for his left lower extremity was normal. The boy was able to perform passive range of motion of his toes with moderate pain. He was splinted initially in ED and returned 4 days after injury for radiographic surveillance and CT scan. Four days after the fracture, the boy presents with continued, moderate pain in his distal extremity, but no neurovascular compromise. The CT scan showed a

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5 millimeter (mm) displacement of the distal tibial plafond (articular surface of the distal tibia) in the axial views. A coronal view showed 3.5 mm of displacement and a faint lucency through the anterolateral aspect of the talar dome. A small nondisplaced fracture could not be excluded. With greater than 2 mm of articular displacement, operative treatment was recommended. An open reduction with internal fixation (ORIF) of the left distal tibial plafond was performed. He was placed in a non-weight-bearing short leg cast for the first 6 weeks after surgery. After immobilization he began physical therapy for passive range of motion of the ankle. Protected weight-bearing with crutches was allowed starting at 6 weeks post injury.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

1. Acute epiphyseal intra-articular displaced fracture in left distal tibia including Salter-Harris type III fracture.
2. Swelling of the left ankle with potential for extensor retinaculum compartment syndrome.

3. Epiphyseal growth remaining in the left distal tibia – unlikely in this patient with limited growth remaining and radiographic signs of physeal closure. Injury in patient with substantial growth remaining could cause premature physeal closure with growth arrest leading to angular deformity of the ankle and lower limb length discrepancy.

4 Treatment Strategy

Due to the characteristic fracture with physeal lesion and the intra-articular displacement (≥ 2 mm), surgery was recommended. The leg was prepped and draped in a sterile fashion, and the leg exsanguinated by gravity. The tourniquet was raised to 250 mmHg, and a 3-cm incision was made along the medial malleolus anteriorly to the most prominent portion of the malleolus. Soft tissues were bluntly dissected down to the level of the periosteum, protecting the greater saphenous vein and nerve. After the fracture was directly visualized, the border of the malleolus was identified, and a reduction clamp was placed on the tip of the malleolus and over the anterior border of the tibia to facilitate reduction. The reduction was confirmed by visualization of the anterior and distal tibial articular surfaces. Then, two guidewires were passed parallel to the articular surface in the epiphysis and across the fracture site. This pattern is perpendicular to the epiphyseal fracture



Fig. 1 (a) Anteroposterior, (b) mortise, and (c) lateral radiographic views of the left ankle show nondisplaced distal tibia Salter Harris type III fracture in a 13-year-old boy

Fig. 2 Four days after the trauma, CT scan shows (a) axial image on left distal tibial articular surface showing a 5 mm displacement, (b) coronal image shows a 3.5 mm, and (c) another coronal view shows, also, a nondisplaced fracture in the anterolateral aspect of the talar dome

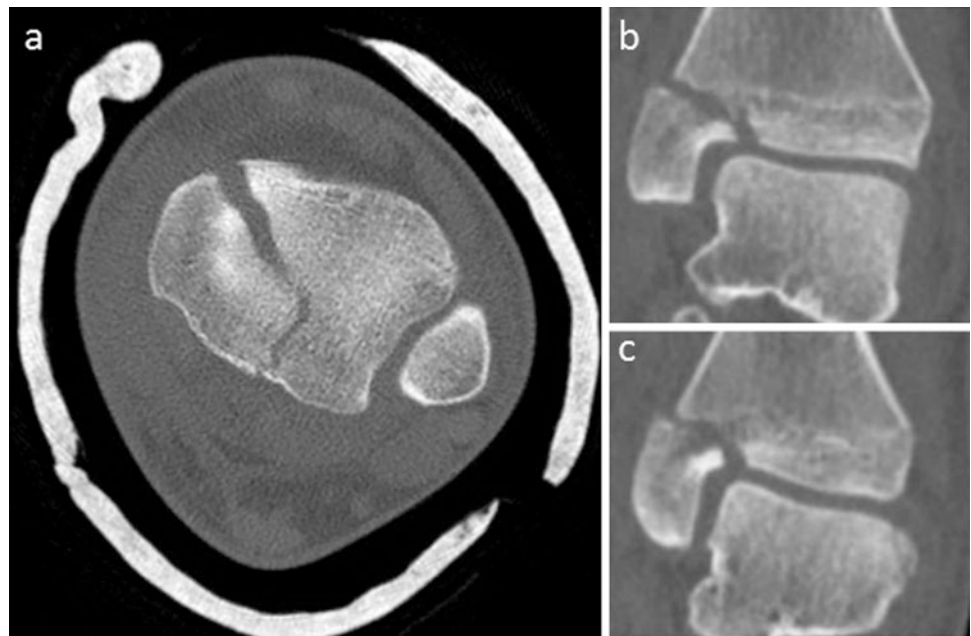


Fig. 3 CT scan with 3D reconstruction shows a left distal tibia epiphyseal fragment: (a) anterior view; (b) posterior view



line and gives compression and stability. The final position of the K-wires was verified with fluoroscopy, and the outer cortex was then drilled. Two partially threaded cancellous screws were placed across the fracture site to provide compression. The articular surface was anatomically reduced, and the screw position was verified not to penetrate the joint. After surgical wound and skin management, a well-padded short leg cast was applied with the ankle in neutral position.

5 Basic Principles

There is a consensus that displaced (≥ 2 mm) distal tibia Salter-Harris type III and IV (articular fractures) should be treated with open reduction and internal fixation. Salter and Harris recommended “accurate” and “perfect” reductions for type III and IV fractures to prevent premature physal

closure. Patients with Salter-Harris type III and IV fractures with >2 mm of displacement with anatomic open reduction and internal fixation were less likely to have a premature physal closure than those treated by closed reduction (Kling et al. 1984). Although the “2-mm rule” is commonly accepted, there is not clear scientific evidence for what represents an acceptable reduction in pediatric distal tibia intra-articular fractures (Blackburn et al. 2012). Non-displaced fractures (<2 mm) can be treated by a long leg, non-weight-bearing cast for 4 weeks, followed by a boot or short leg cast for 4 weeks. The first 2 weeks in the boot or cast should remain non-weight-bearing (Podeszwa and Mubarak 2012). In older patients where there is not a concern for growth arrest, the principle guiding decision for surgical treatment is restoration of an anatomic articular surface to lessen the chances of developing post-traumatic arthrosis.

Fig. 4 (a) Intraoperative fluoroscopic with direction of guidewire parallel to articular tibial plafond surface and distal tibia physis, (b) anteroposterior view, (c) mortise view, (d) and lateral radiographic view show good position of screws which do not across articular surface or physis. In older patients like this crossing, the physis would be acceptable



6 Images During Treatment

See Fig. 4.

7 Technical Pearls

1. Axial CT scan view can provide accurate assessment of intra-articular displacement and is helpful for planning screw trajectory. Linking multiple planes (axial, coronal, and sagittal) together in one view can further clarify screw trajectory.
2. Fluoroscopy is necessary to check the positioning of screw in anteroposterior, mortise, and lateral views.
3. Reduction of displaced (≥ 2 mm) distal tibia Salter-Harris III should be assessed by open reduction with direct visualization of the medial corner and anterior articular surface. Fragments of the bone can be in the joint. In addition,

visualization allows confidence in anatomic reduction which may not be proven on fluoroscopic imaging alone. After a gentle reduction of fracture, a bone clamp can be used to maintain the reduction. One or two partially threaded screws must cross the line of fracture and avoid crossing the physis and articular surface in a skeletally immature child.

4. Radiographic evaluation requires three radiographic views for the ankle: anteroposterior, mortise, and lateral views.
5. A CT scan is useful to understand fracture anatomy and to plan screw placement. The CT scan may give additional information which changes treatment decisions (Thawrani et al. 2011).

8 Outcome Clinical Photos and Radiographs

See Figs. 5 and 6.

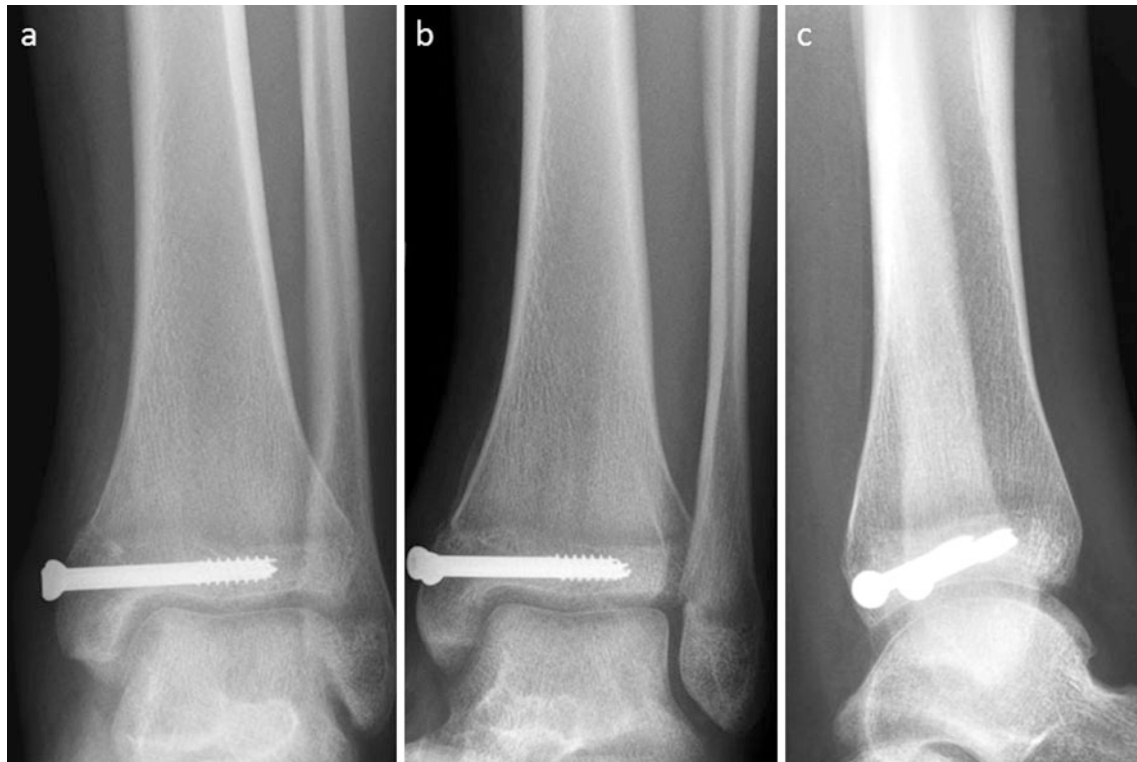


Fig. 5 Six weeks postoperative radiographs show healing of fracture in (a) anteroposterior, (b) mortise, and (c) lateral views. The Hawkins sign or sclerosis in the talar dome demonstrates good revascularization and healing of anterolateral talar dome fracture



Fig. 6 Radiographs of left ankle 8 months after surgery show a closed physis, with no angular (varus) deformity in (a) anteroposterior, (b) mortise, and (c) lateral views. Also, clinically there is no lower limb discrepancy

9 Avoiding and Managing Problems

1. Closed reduction or nonanatomical reduction for displaced intra-articular fractures after open approach can develop growth arrest, leading to angular deformities and lower limb discrepancy (Spiegel et al. 1978).
2. Any fracture with ≥ 2 mm displacement should be anatomically reduced to minimize the risk of premature physeal closure, prevent joint incongruity, and minimize the risk of subsequent early degenerative arthritis (Podeszwa and Mubarak 2012).
3. Serial ankle radiographs should be performed every 6 months for a minimum of 2 years to monitor for a distal tibial growth arrest (Podeszwa and Mubarak 2012).
4. Removal of epiphyseal implants is recommended as the total force transmission, and peak contact pressures are significantly increased over baseline with the presence of epiphyseal screws (Charlton et al. 2005).

References and Suggested Readings

- Blackburn EW, Aronsson DD, Rubright JH, Lisle JW (2012) Ankle fractures in children. *J Bone Joint Surg. American* Volume 94(13): 1234–1244
- Charlton M, Costello R, Mooney JF 3rd, Podeszwa DA (2005) Ankle joint biomechanics following transepiphyseal screw fixation of the distal tibia. *J Pediatr Orthop* 25(5):635–640
- Kling TF Jr, Bright RW, Hensinger RN (1984) Distal tibial physeal fractures in children that may require open reduction. *J Bone Joint Surg. American* Volume 66(5):647–657
- Podeszwa DA, Mubarak SJ (2012) Physeal fractures of the distal tibia and fibula (Salter-Harris Type I, II, III, and IV fractures). *J Pediatr Orthop* 32(Suppl 1):S62–S68
- Spiegel PG, Cooperman DR, Laros GS (1978) Epiphyseal fractures of the distal ends of the tibia and fibula. A retrospective study of two hundred and thirty-seven cases in children. *J Bone Joint Surg. American* Volume 60(8):1046–1050
- Thawrani D, Kuester V, Gabos PG, Kruse RW, Littleton AG, Rogers KJ, Holmes L, Thacker MM (2011) Reliability and necessity of computerized tomography in distal tibial physeal injuries. *J Pediatr Orthop* 31(7):745–750

10 Cross-References

- [Salter-Harris II Distal Tibia and Fibula Fractures](#)

Isolated Lateral Malleolus Fracture

Scott J. Schoenleber

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Abstract

Fractures of the lateral malleolus in the skeletally immature patient are relatively common. Although in many cases these are associated with fractures of the distal tibia, the distal fibula may be fractured in isolation. In the majority of these, the fracture is non-displaced and diagnosed on the basis of soft tissue swelling and tenderness at the level of the distal fibular physis. Additionally, displaced Salter-Harris types I and II patterns may be seen. These occur most commonly in patients between the ages of 10 and 12 years. The mechanism of injury is typically due to supination-inversion. Treatment of non-displaced fractures may be safely performed either with a short leg walking cast or a brace, depending on surgeon and patient preference. Displaced fractures should be reduced and

immobilized in a non-weightbearing cast for 4–6 weeks. While growth arrest and shortening have both been reported in a small number of patients with type I fractures, complications with type II fractures remain rare.

1 Brief Clinical History

This 7-year-old patient presented after a twisting injury to the ankle while on a skateboard. On initial presentation, there was moderate swelling, ecchymosis, and an obvious deformity laterally with tenderness to palpation. There were no other injuries and no tenderness to palpation or ecchymosis over the distal tibia or deltoid ligament. The patient had a normal neurovascular examination and the skin was intact. The patient was initially seen at an outside facility where a closed reduction under sedation was attempted unsuccessfully, so they were transferred to our facility for definitive management.

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Fig. 1 Anteroposterior (AP) radiograph showing displacement at time of injury



Fig. 2 Mortise view

2 Preoperative Clinical Photos and Radiographs

Injury anteroposterior (AP) (Fig. 1), mortise (Fig. 2), and lateral (Fig. 3) radiographs demonstrate a posteriorly displaced Salter-Harris II fracture of the lateral malleolus. There is a posterior metaphyseal Thurstan-Holland fragment evident on the lateral view.

3 Preoperative Problem List

1. Posteriorly displaced Salter-Harris II fracture of the lateral malleolus
2. Skeletally immature patient
3. Previous unsuccessful attempt at closed reduction

4 Treatment Strategy

Given the amount of displacement and the previous unsuccessful attempt at a closed reduction, the patient was scheduled for the operating room to achieve adequate muscle relaxation with general anesthesia and to address any

potential impediments to reduction. A stepwise approach to fracture management was planned, with closed reduction resulting in anatomic alignment in this case. If this had not been successful, an open reduction would have been indicated through a longitudinal incision centered over the physis to remove any interposed tissue and achieve congruency. In either case, if the reduction was felt to be unstable, a single 0.062-inch Kirschner wire could be utilized to achieve additional stability.

5 Basic Principles

In all fractures, but especially physeal fractures that may be amenable to closed management alone, adequate muscle relaxation is essential during initial management. This allows for gentle fracture reduction to minimize additional trauma to the physis. In this case, closed reduction in the emergency room was not successful, but once adequate muscle relaxation was achieved with general anesthesia, the fracture was easily reduced. In most cases, patients can be managed in a long or short leg cast for 4–6 weeks (Podeszwa and Mubarak 2012). Internal fixation is not typically required. Occult fractures may be managed with either a cast or brace for 3–4 weeks (Sankar et al. 2008).

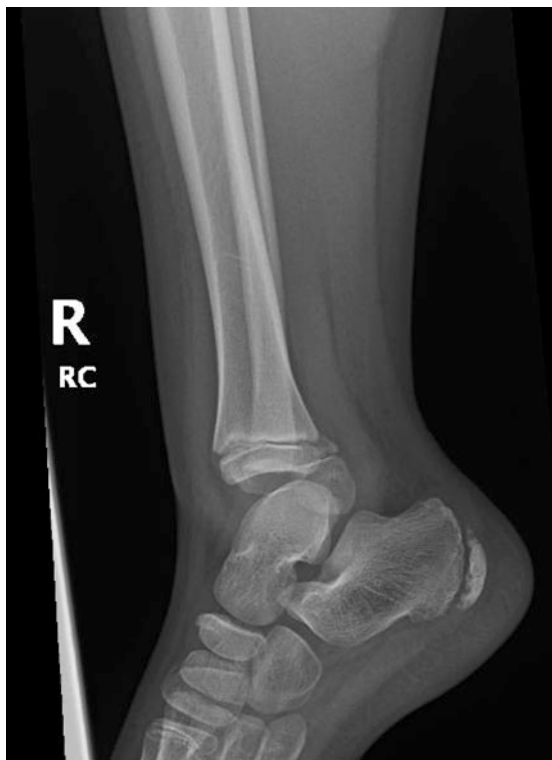


Fig. 3 Lateral view showing posterior displacement



Fig. 4 Successful closed reduction seen on AP view

6 Images During Treatment

Anteroposterior (AP) (Fig. 4), mortise (Fig. 5), and lateral (Fig. 6) radiographs immediately following surgery demonstrate an anatomic reduction without any asymmetry of the physis.

7 Technical Pearls

Adequate relaxation is essential to optimize the chances of a successful closed reduction, which can be achieved in most cases. Repeated forceful attempts at closed reduction should be avoided. For the rare cases where closed reduction is unsuccessful, general surgical principles apply. Typically a small incision centered over the distal fibular physis is sufficient to remove interposed periosteum and achieve alignment. If the resulting reduction is still unstable, a 0.062-inch Kirschner wire can be placed obliquely from the epiphysis to the metaphysis to achieve additional stability.

8 Outcome Clinical Photos and Radiographs

Anteroposterior (Fig. 7), mortise (Fig. 8), and lateral (Fig. 9) radiographs obtained at 4 weeks demonstrate maintenance of reduction with evidence of mineralized callus formation. At this point, the patient was converted to a short leg cast for an additional 3 weeks.

At 2 months, anteroposterior (Fig. 10), mortise (Fig. 11), and lateral (Fig. 12) radiographs out of the cast demonstrate complete healing with no early evidence of deformity.

9 Avoiding and Managing Problems

Management of isolated distal fibular physeal fractures is predicated on ensuring that there is no other apparent injury, as distal tibial physeal fractures are commonly seen in conjunction with distal fibular fractures (Spiegel et al. 1978; Podeszwa and Mubarak 2012). The risk for complications following occult fractures is likely very low. For patients with unequivocal fractures, the risk depends on the fracture pattern. In a large series, 3 of 16 (18.8%) patients with Salter-Harris type I fractures were reported to have complications consisting of premature growth arrest and fibular shortening (Spiegel et al. 1978). None of the five patients with type II fractures had sustained complications (Spiegel et al. 1978). Due to this risk, we routinely monitor patients with displaced fractures for growth arrest and shortening for 1 to 2 years.



Fig. 5 Mortise view immediately after closed reduction



Fig. 7 AP view showing maintained alignment and early healing at 4 weeks



Fig. 6 Lateral view showing anatomic alignment



Fig. 8 Mortise view showing maintained alignment and early healing at 4 weeks



Fig. 9 Lateral view showing maintained alignment and early healing at 4 weeks



Fig. 11 Mortise view showing omplete consolidation at 2 months



Fig. 10 AP view showing omplete consolidation at 2 months



Fig. 12 Lateral view showing omplete consolidation at 2 months

10 Cross-References

► [Salter-Harris II Distal Tibia and Fibula Fractures](#)

References and Suggested Reading

Podeszwa DA, Mubarak SJ (2012) Physeal fractures of the distal tibia and fibula (Salter-Harris type I, II, III, and IV fractures). *J Pediatr Orthop* 32:S62–S68

Sankar WN, Chen J, Kay RM, Skaggs DL (2008) Incidence of occult fracture in children with acute ankle injuries. *J Pediatr Orthop* 28:500–501

Spiegel PG, Cooperman DR, Laros GS (1978) Epiphyseal fractures of the distal ends of the tibia and fibula. *J Bone Joint Surg (Am)* 60-A:1046–1050

Triplane Distal Tibia Fractures

Daniel Komlos and Mara Karamitopoulos

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Abstract

Pediatric triplane fractures of the distal tibia typically occur in the early teenage years, peaking around 13–14 yrs old and account for about 4–15% of pediatric ankle fractures, are transitional physeal fractures, with asymmetric closure of the distal tibial physis leading to a three-dimensional fracture pattern of an overall Salter-Harris IV fracture that may be 2, 3, or 4 part fractures. Plain radiographs often underestimate the true displacement of fracture fragments, therefore a computed tomography (CT) scan is needed for further evaluation due to the complexity of the fracture. Displacement of >2 mm at the epiphysis generally requires operative management to reestablish articular congruency at the distal tibia and minimizes the risks of degenerative changes

and early physeal closure. Fixation typically involves lag screws to reduce fragments and can be performed open or percutaneously. Patients are then casted for 4–6 weeks following fixation before beginning progressive weight bearing.

1 Brief Clinical History

A 13-year-old male presents with left ankle pain and swelling after getting his foot stuck in his bike spoke. Radiographs show a Salter-Harris III fracture of the distal tibia on the anterior-posterior (AP) view and a Salter-Harris IV fracture on the lateral view. A CT scan was obtained showing increased displacement as well as some rotation of the epiphysis.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 2, 3, 4, and 5.

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Fig. 1 Preoperative AP radiograph of the left ankle

3 Preoperative Problem List

- Displacement of distal tibial epiphysis

4 Treatment Strategy

Closed reduction under sedation and long-leg casting may be attempted at initial presentation. Radiographs often underestimate the true displacement of the fracture. A postreduction CT scan is needed due to the multiplanar characteristic of the fracture. If the fracture can be closed and reduced with less than 2 mm displacement, long-leg casting can be used with favorable outcomes (Cooperman et al. 1978). For fractures with >2 mm displacement, open reduction and internal fixation is recommended. Operative fixation involves either percutaneous screw fixation or open reduction typically using an anterolateral approach.



Fig. 2 Preoperative oblique radiograph of the left ankle

5 Basic Principles

Triplane fractures are seen in the early teenage years due to the pattern of physeal closure of the distal tibia. Closure begins relatively centrally, then progresses anteromedially and posteromedially. Final closure occurs at the lateral aspect of the distal tibia, and the direction of fracture propagation results in a three-dimensional pattern that requires anterior-posterior (AP) and lateral ankle X-rays for full appreciation. These represent a three-dimensional Salter-Harris IV fracture (Kling 1990), consisting of fractures in the coronal, sagittal, and transverse planes. Triplane fractures can have two, three, or four parts, all involving a metaphyseal and epiphyseal component. Failure to achieve and maintain adequate reduction at the epiphysis can lead to early arthritis and possible early physeal closure.

6 Images During Treatment

See Figs. 6 and 7.

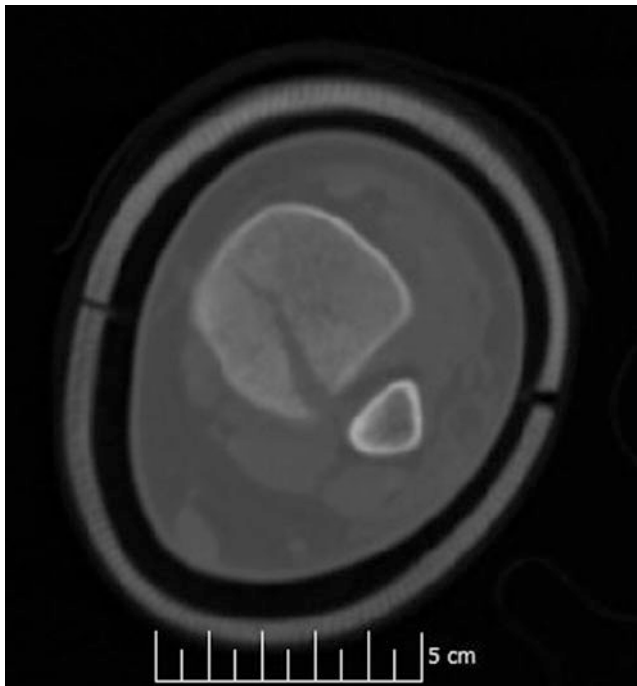


Fig. 3 Preoperative lateral radiograph of the left ankle

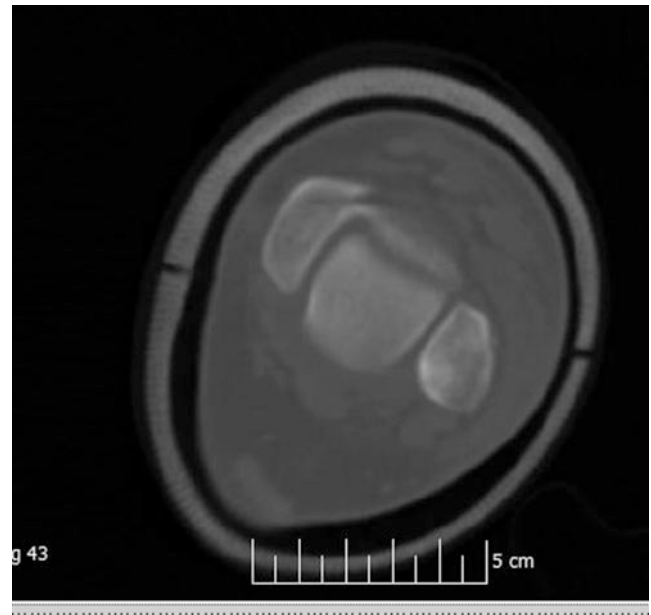


Fig. 5 Sagittal CT image showing intra-articular widening of Salter-Harris IV fracture

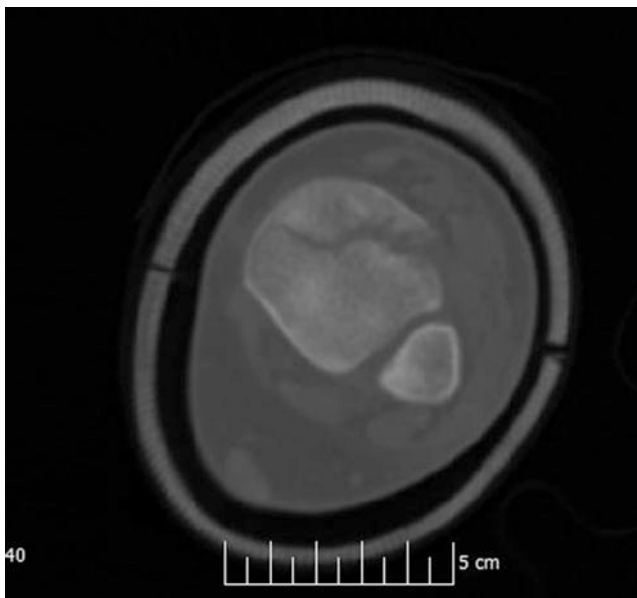


Fig. 4 Coronal CT image showing widening of rotation of the epiphyseal fragment

7 Technical Pearls

Preoperative use of CT scan is of great importance for preoperative planning and for greater understanding of the fracture pattern. While closed reduction of the fracture can be



Fig. 6 Intraoperative fluoroscopic AP showing cannulated screw placement



Fig. 7 Intraoperative fluoroscopic image showing screw placement in the lateral view



Fig. 9 Postoperative lateral radiograph at 6 weeks



Fig. 8 Postoperative AP radiograph at 6 weeks after open reductions and internal fixation

attempted in the operating room, open reduction is often needed in significantly displaced triplane fractures. Interposed periosteum often blocks congruent reduction. Surgical approach is determined by the characteristics of the fracture. Generally, one to two lag screws are needed from anterior to posterior in the metaphyseal segment. One lag screw placed as parallel as possible to the tibial plafond helps reduce the epiphyseal segment. Often, this requires two incisions for optimal access to the fracture. Caution must be taken not to penetrate the joint with placement of the epiphyseal screw. Intraoperative live fluoroscopy can be helpful to ensure that the epiphyseal screw is not intraarticular.

8 Outcome Clinical Photos and Radiographs

See Figs. 8 and 9.

9 Avoiding and Managing Problems

The most important component of surgical management is adequate reduction, particularly at the articular surface. Residual displacement of greater than 2 mm in the weight-



Fig. 10 Intra-operative lateral radiograph showing 3 partially threaded screws

bearing portion of the articular surface has been associated with suboptimal outcomes within a 36-month period in some studies (Ertl et al. 1988). While physeal closure is an additional concern, triplane fractures typically occurs at ages close to skeletal maturity, and contributes about 4–6 mm of overall growth per year (Crawford 1995). Children should be followed with radiographs until skeletal maturity; and bilateral weight-bearing radiographs can be obtained, should there be a concern about angular deformity or premature closure (Figs. 10 and 11).



Fig. 11 Intra-operative AP radiograph showing 3 partially threaded screws

References and Suggested Reading

- Cooperman DR, Spiegel PG, Laros GS (1978) Tibial fractures involving the ankle in children: the so-called triplane epiphyseal fracture. *J Bone Joint Surg Am* 60(8):1040–1046
- Crawford AH (1995) Ankle fractures in children. *Instr Course Lect* 44:317–324
- Ertl JP, Barrack RL, Alexander AH et al (1988) Triplane fracture of the distal tibial epiphysis long-term follow-up. *J Bone Joint Surg Am* 70A(7):967–976
- Kling TF Jr (1990) Operative treatment of ankle fractures in children. *Orthop Clin North* 21:381–392

Management of Tillaux Fractures

Sheriff Akinleye and Mara Karamitopoulos

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Abstract

Adolescents are susceptible to relatively uncommon Salter Harris III fractures of the distal tibia, known as Tillaux fractures. This is due to the fact that the closure of the distal tibia physis occurs over an 18-month period between the ages of 12 and 15 years. Thus, in the setting of an external rotation force to the distal tibia during this specific period of time, a Tillaux fracture can occur. Following closed reduction in a long leg cast, computed tomography (CT) scans are needed to adequately assess joint congruity. This is critical, as a gap of 2 mm or more can lead to residual deformity of the articular surface resulting in premature degenerative arthritis of the ankle joint. Therefore, in order to ensure accuracy of fixation, these periarticular fractures are usually treated with cannulated screws. Regardless of the treatment modality, anatomic reduction of the articular surface is the goal of care.

1 Brief Clinical History

A 13-year-old female with no past medical history presents to the emergency room after twisting her ankle stepping off a curb. Radiographs demonstrated a distal epiphyseal tibia fracture. The patient was placed in a long leg cast and sent for a CT scan of the left ankle. CT scan displayed persistent articular displacement of >2 mm.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, 5, and 6.

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Fig. 1 AP radiograph of left ankle



Fig. 2 Oblique radiograph of left ankle

3 Preoperative Problem List

1. Inadequate reduction of distal tibia epiphysis.

3.1 Treatment Strategy

The initial treatment of a displaced Tillaux fracture consists of closed reduction of distal tibia utilizing traction and internal rotation. The patient is then placed in a long leg cast to attain optimal rotational stability. Postreduction radiographs and CT scan should be obtained to evaluate the reduction of the articular surface. Operative intervention should be considered if there is a gap of more than 2 mm. Treatment options include closed versus open reduction of the fracture and internal fixation with cannulated screws. Utilizing the anterolateral approach, the fracture was visualized, directly

reduced, followed by insertion of a cancellous screw through the epiphysis.

3.2 Basic Principles

The Tillaux fracture, classified as a Salter Harris III fracture, is a vertical intraarticular fracture through the epiphysis of the distal tibia, extending laterally across the open physis (Canale 1992). The distal tibia physis closes in a predictable manner in adolescents between the ages of 12 and 15, with the lateral physis closing last, making it susceptible to this pattern of injury (Simon et al. 1989). Given the fact that the surrounding ligaments and joint capsule are stronger than the open physis, the external rotation force with stress on the anterolateral fibular ligament leads to avulsion of the distal tibia epiphysis anterolaterally (Canale 1992). Inadequate joint reduction



Fig. 3 Lateral radiograph of left ankle

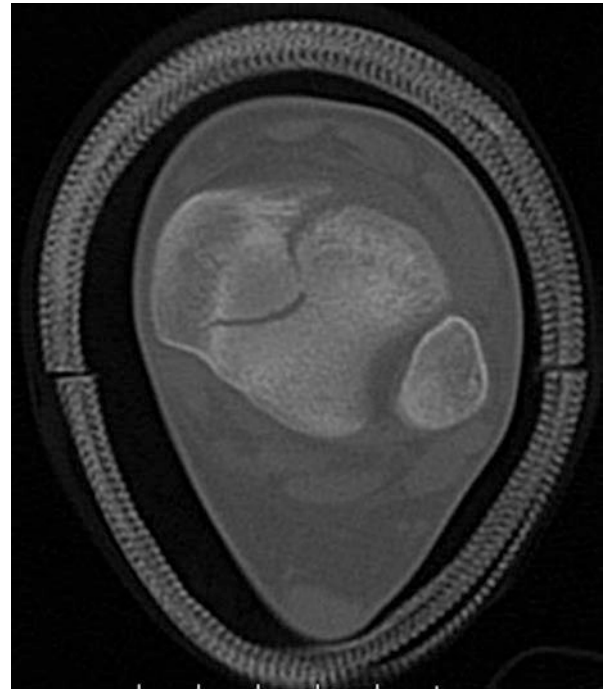


Fig. 5 Axial image of left ankle CT scan



Fig. 4 Coronal image of left ankle CT scan



Fig. 6 Sagittal image of left ankle CT scan



Fig. 7 Intraoperative fluoroscopy displaying AP of left ankle



Fig. 8 Intraoperative fluoroscopy displaying left ankle mortise view



Fig. 9 Intraoperative fluoroscopy displaying lateral of left ankle

of more than 2 mm can lead to the development of degenerative arthritis and is the primary concern when treating Tillaux fractures. This fracture is of great importance, as the distal tibia is a major weight-bearing articular surface. Residual deformity can lead to great morbidity (Leitch et al. 1989).

3.3 Images During Treatment

See Figs. 7, 8, and 9.

4 Technical Pearls

Closed reduction occurs with axial traction and an internal rotation force at the ankle joint in order to reverse the mechanism of injury. If closed reduction is achieved in the operating room, percutaneous screws can be placed. An open anterolateral approach is used to address the displaced distal tibia epiphyseal fragment (Kling 1990). A guidewire is inserted perpendicular to the fracture within the epiphysis, parallel to the tibial plafond, in order to ensure accuracy of screw placement. Once the trajectory



Fig. 10 AP radiograph of left ankle at 6-week follow up



Fig. 11 Lateral radiograph of left ankle at 6-week follow up

and alignment of the guidewire are deemed satisfactory, a cannulated lag screw is placed in order to achieve interfragmentary compression within the epiphysis. This technique minimizes disruption of the physis, theoretically preventing premature physeal closure (Duchesneau and Fallat 1996).

5 Outcome Clinical Photos and Radiographs

See Figs. 10, 11, 12, and 13.

6 Avoiding and Managing Problems

Growth arrest is of little concern in Tillaux fractures because closure of the physis is already occurring in this pattern of injury (Barmada et al. 2003). The major concern is posttraumatic arthritis due to residual deformity of the articular surface of this critical weight bearing joint (Leitch et al. 1989). It is necessary to obtain computed tomography scans of the ankle joint to ensure adequate reduction, which is less than 2 mm of displacement. If not adequately reduced, operative intervention should be considered.



Fig. 12 AP radiograph of left ankle at 6-month follow up



Fig. 13 Lateral radiograph of left ankle at 6-month follow up

7 Cross-References

► Triplane Distal Tibia Fractures

References and Suggested Reading

- Canale TS (1992) Fractures and dislocations in children. In: Crenshaw AH (ed) *Campbell's operative orthopedics*. Mosby, St. Louis, pp 1213–1218
- Simon WH, Floros R, Schoenhaus H et al (1989) Juvenile fracture of Tillaux: a distal tibial epiphyseal fracture. *J Am Podiatr Med Assoc* 79(6):295–299
- Leitch JM, Cundy PJ, Paterson DC (1990) Three-dimensional imaging of a juvenile Tillaux fracture. *J Pediatr Orthop* 9(5):602–603
- Kling TF, Jr. (1990) Operative treatment of ankle fractures in children. *Orthop Clin North Am* 21(2):381–392.
- Duchesneau S, Fallat LM (1996) The Tillaux fracture. *J Foot Ankle Surg* 35(2):127–133
- Barmada A, Gaynor T, Mubarak SJ (2003) Premature physeal closure following distal tibia physeal fractures: a new radiographic predictor. *J Pediatr Orthop* 23(6):733–739

Isolated Medial Malleolus Fracture

Scott J. Schoenleber

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Abstract

Fractures of the medial malleolus represent Salter-Harris III fractures that occur as a result of a supination-inversion mechanism at an average age of between 11 and 12 years. These can be isolated medial malleolus fractures (approximately 75% of cases) or can have an associated distal fibula fracture (25% of cases). Treatment is dictated by the amount of fracture displacement, with greater than 2 mm of residual displacement following closed reduction meeting the criteria for open reduction and internal fixation. In nondisplaced or minimally displaced fractures, treatment consists of a nonweightbearing long leg cast for 4 weeks followed by an additional 4 weeks in a short leg cast. For displaced fractures, operative management results in excellent restoration of the articular surface, but these

fractures carry a significant risk of complications. Patients should be followed over the long-term to evaluate for physeal arrest, angular deformity, or leg length discrepancy, which may occur in 11–15% of patients. These complications may develop in operatively or non-operatively treated fractures and may be related to the amount of initial fracture displacement or the quality of reduction.

1 Brief Clinical History

This 10-year-old child sustained a twisting injury to the ankle while playing on a trampoline. At initial presentation to our facility several days after injury, the patient had inability to bear weight, pain, swelling, and ecchymosis. There were no abrasions or lacerations, no proximal tenderness to palpation, and the neurovascular examination was normal. Radiographic evaluation demonstrated a comminuted Salter-Harris III fracture of the medial malleolus with 3 mm of displacement and a concomitant avulsion fracture of the distal tip of

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Fig. 1 Injury anteroposterior (AP) radiograph demonstrating a comminuted, mildly displaced medial malleolar Salter-Harris III fracture



Fig. 2 Mortise view

the lateral malleolar epiphysis. The child reported a history of multiple previous ankle sprains.

2 Preoperative Clinical Photos and Radiographs

Injury anteroposterior (Fig. 1), mortise (Fig. 2), and lateral (Fig. 3) radiographs demonstrate a skeletally immature patient with a comminuted mildly displaced fracture of the medial malleolus and a distal avulsion fracture of the lateral malleolus, with some sclerotic and cystic margins suggestive of prior injury.

3 Preoperative Problem List

1. Displaced Salter-Harris III fracture of the medial malleolus with comminution
2. Distal avulsion fracture of the lateral malleolus, with sclerotic margins and acute soft tissue swelling suggesting acute on chronic injury
3. Skeletally immature patient with growth remaining

4 Treatment Strategy

The approach to this injury was dictated by the amount of displacement (3 mm) and the degree of comminution. Because this fracture was amenable to closed reduction in the operating room, a percutaneous technique was utilized. Multiple partially threaded screws allowed compression across the fracture site, which was augmented by the use of washers due to the comminution. The distal fibula avulsion was treated nonoperatively due to the very distal nature of the fracture and the excellent intraoperative alignment that was achieved. Postoperatively, the patient was immobilized in a short leg nonweightbearing cast for 4 weeks, followed by immobilization and progressive weightbearing over the course of the subsequent 4 weeks.

5 Basic Principles

The principles underlying treatment of this injury are restoration of the alignment, preservation of the physis, and congruence of the articular surface. This is best achieved with rigid internal fixation when possible, which both allows for



Fig. 3 Lateral view shows minimal sagittal plane translation



Fig. 4 Intraoperative AP fluoroscopy image shows restoration of alignment, with partially threaded screw and washer placement within the epiphysis. The lateral malleolus fragment appears well aligned

primary healing and decreases the amount and type of immobilization that is required. To achieve optimal fixation and assess congruence of the joint, axial imaging such as computed tomography may be helpful preoperatively to aid in



Fig. 5 Intraoperative mortise view

surgical planning. During any treatment method, reduction attempts should be minimized and performed with muscle relaxation so that further damage to the physis can be minimized. Optimal outcomes may be achieved with anatomic reduction.

6 Images During Treatment

Intraoperative AP (Fig. 4), mortise (Fig. 5), and lateral (Fig. 6) fluoroscopy images demonstrating reduction of the main fracture fragment with restoration of the articular surface.

7 Technical Pearls

Mildly displaced fractures can be addressed with a percutaneous technique. For displaced fractures, a curvilinear medial incision allows for excellent exposure when open reduction is required. Dissection can be carried out anteriorly and a small arthrotomy can be performed when necessary to expose the articular margin and evaluate the presence of articular surface impaction. A large periarticular clamp can aid with reduction while guidewires are placed. In cases with articular impaction, the arthrotomy is allowed for direct visualization in which the subchondral bone is elevated with a freer elevator. In rare high-energy injuries with extreme impaction, subchondral rafting wires can be placed parallel to the joint to support the articular surface. Definitive fixation is achieved according to the major fracture pattern and



Fig. 6 Intraoperative lateral view



Fig. 8 Mortise view



Fig. 7 Six-month follow-up AP radiograph shows a healed fracture with maintained alignment and stable implants. Several months later, the implants were removed (images not shown)

the level of skeletal maturity. For immature patients, use two 4.0-mm cannulated epiphyseal screws (as in this case) or multiple 0.062 smooth Kirschner wires if screw fixation is not possible. For mature patients, fixation is chosen based on the fracture pattern and may include 4.0 mm cannulated screws, antiglide plates, or tension band wiring as necessary. A washer is optional but may be helpful in cases with comminution.

8 Outcome Clinical Photos and Radiographs

Six-month postoperative AP (Fig. 7), mortise (Fig. 8), and lateral (Fig. 9) follow-up radiographs show a healed fracture with maintained alignment and stable implants. Several months later, the implants were removed (images not shown).

9 Avoiding and Managing Problems

Nonoperatively treated fractures warrant close radiographic follow-up during the first two weeks after injury, to identify and manage loss of reduction. If reduction is unable to be achieved by closed means, there may be interposed tissue, which should be removed. Anatomic reduction is essential to minimize the long-term risk of degenerative arthritis and may also help to minimize physeal arrest (Spiegel et al. 1978; Kling et al. 1984). Patients should be followed over the long-term to evaluate this and other late complications, such



Fig. 9 Lateral view at follow-up

as distal tibial varus deformity or leg length discrepancy, which may occur in 11–15% of patients (Leary et al. 2009; Nenopoulos et al. 2005). These complications may develop in operatively or nonoperatively treated fractures and may be related to the amount of initial fracture displacement (Leary et al. 2009) or the quality of reduction (Spiegel et al. 1978; Kling et al. 1984). If growth arrest is suspected, an MRI or CT is performed to map the degree of involvement and guide further management. Implant-related complaints may occur in all types of ankle fractures, and implant removal after fracture healing is appropriate in symptomatic children,

young children with significant growth remaining, and in cases where the implant is juxta- or trans-physeal and has served its purpose (Jacobsen et al. 1994; Gugala and Lindsey 2015).

10 Cross-References

- Isolated Lateral Malleolus Fracture
- Salter-Harris II Distal Tibia and Fibula Fractures
- Salter-Harris III Distal Tibia Fracture

References and Suggested Readings

- Cummings RJ, Shea KG (2010) Distal tibial and fibular fractures. In: Beaty JM, Kasser JR (eds) Rockwood and Wilkins' fractures in children, 7th edn. Lippincott Williams & Wilkins, Philadelphia, pp 986–989
- Gugala Z, Lindsey RW (2015) Removal versus retention of orthopaedic trauma implants. *Orthop Knowl Online J* 13:2
- Jacobsen S, Honnens de Lichtenberg M, Jensen CM, Tørholm C (1994) Removal of internal fixation – the effect on patients' complaints: a study of 66 cases of removal of internal fixation after malleolar fractures. *Foot Ankle Int* 15:170–171
- Kling TF, Bright RW, Hensinger RN (1984) Distal tibial physeal fractures in children that may require open reduction. *J Bone Joint Surg Am* 66-A:647–657
- Leary JT, Handling M, Talerico M, Yong L, Bowe JA (2009) Physeal fractures of the distal tibia: predictive factors of premature physeal closure and growth arrest. *J Pediatr Orthop* 29:356–361
- Nenopoulos SP, Papavasiliou VA, Papavasiliou AV (2005) Outcome of physeal and epiphyseal injuries of the distal tibia with intra-articular involvement. *J Pediatr Orthop* 25:518–522
- Spiegel PG, Cooperman DR, Laros GS (1978) Epiphyseal fractures of the distal ends of the tibia and fibula. *J Bone Joint Surg Am* 60-A:1046–1050

Talar Fracture

Monica Payares-Lizano

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Abstract

Pediatric talar fractures are very rare and account for less than 10% of all talar fractures reported in the literature. Most of what we know about pediatric fractures comes from adult literature as there are only a few studies in children. Fractures of the neck of the talus are more common than talar body or talar head fractures. The mechanism of injury is dorsiflexion and axial loading. If there is a supination component, it may result in malleolar fractures. In a young child, initial radiographic evidence of fracture can be subtle. As with most children fractures, treatment of young children is usually non-operative, and excellent outcomes can be expected with cast immobilization alone. Treatment of adolescents is more similar to that of adults, with comparable results and a high risk for avascular necrosis (AVN) and post-traumatic arthrosis in

displaced fractures. In recent years due to increased participation in high-impact sports and driving cars, the incidence of talar fractures in children has increased. It is important to understand outcomes and complications of talar fractures in children as great disability can often follow fractures of the talus.

1 Brief Clinical History

The patient is a 16-year-old male basketball player who injured his left foot after landing a jump. The patient was immediately taken to the emergency room for obvious deformity of the left foot and ankle and inability to ambulate. He was found to have both clinical and radiographic evidence of a subtalar dislocation (Fig. 1). He underwent closed reduction under conscious sedation in the emergency room. Post-reduction films showed an adequate reduction of the subtalar joint; however, there was an irregularity around the talar head

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Fig. 1 Initial radiographs. (a) Anteroposterior (AP) radiograph and (b) lateral radiograph showing medial subtalar dislocation



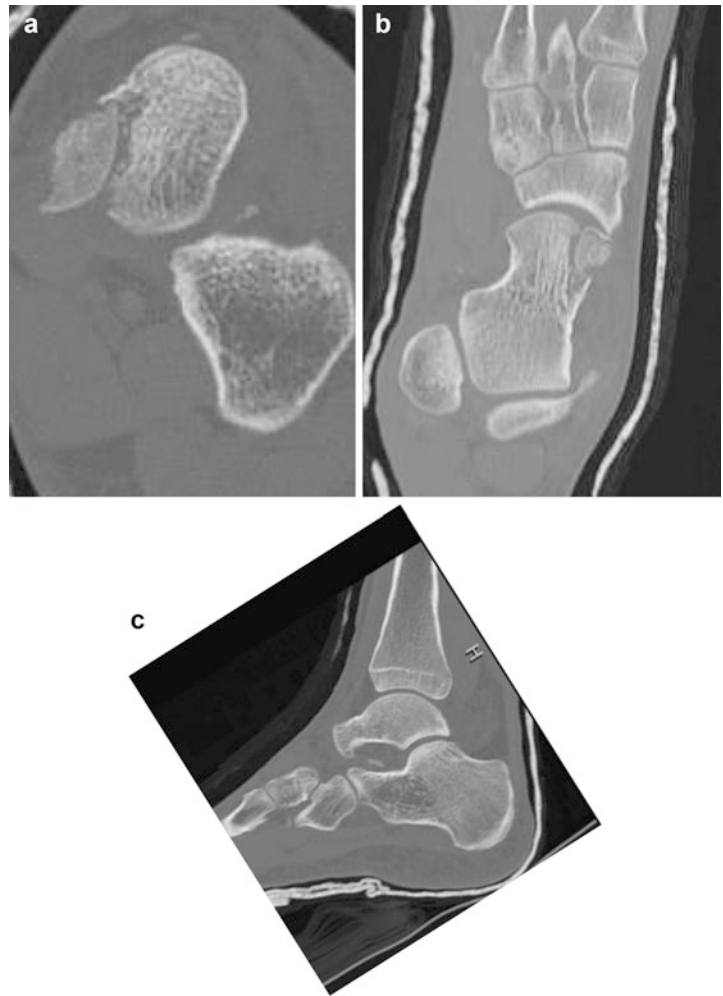
Fig. 2 Postreduction of subtalar dislocation. (a) AP, (b) lateral, and (c) oblique showing reduction of the subtalar joint but evidence of talar head fracture

(Fig. 2). A CT scan was ordered to better assess talar head and possible intra-articular fragments. The CT showed a displaced and rotated medial talar head fracture disrupting the talonavicular joint (Fig. 3). The patient was indicated for open reduction and internal fixation of talar head fracture due to displacement and intra-articular nature of the fracture.

2 Preoperative Clinical Photos and Radiographs

See Figs 1–3.

Fig. 3 CT imaging. (a) Axial, (b) coronal, and (c) sagittal showing displaced talar head fracture and possible fragments in subtalar joint



3 Preoperative Problem List

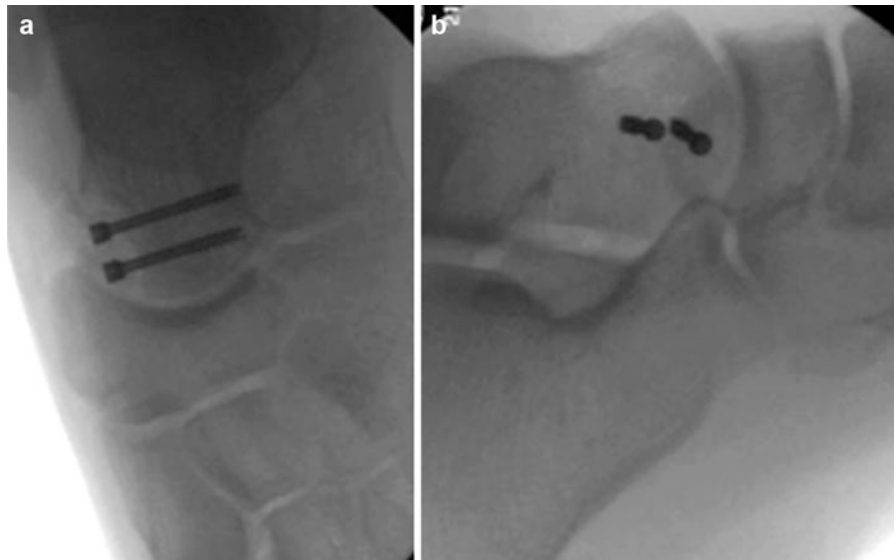
1. Subtalar dislocation
2. Talar head fracture
3. Articular fracture
4. Subtalar intra-articular fragments

4 Treatment Strategy

Due to displacement of the talar head and articular nature of the fracture as well as intra-articular fragments, open reduction with internal fixation was indicated. A standard antero-medial approach to the talar head is utilized. The incision is carried down through the skin and soft tissues to the level of the fracture. The anterior tibial tendon is identified and retracted, and this provides exposure to the talonavicular joint. Depending on the severity of the initial injury, some of the dissection may be done for you, to take advantage of

those planes. In this case soft tissue disruption was found. The joint was opened and the fracture fragment was found. It was rotated 90° to its normal axis. The fracture fragment was mobilized. There was a soft tissue pedicle attached to the proximal portion of the piece. It is important to preserve soft tissue attachment as they can be important in residual vascularity of the fragments. The fracture fragments as well as the fracture bed are gently cleaned of interposing soft tissue as well as debris. The area is then irrigated. The fracture is then reduced and provisionally held with guidewires. In this case 3.0 mm headless, cannulated screws were used. If the fragment allows use of more than one screw, place two guidewires before placing screws to control rotation of the fragments. After proper positioning of the guide pins as confirmed with direct visualization as well as fluoroscopic imaging, two 3.0 mm cannulated headless screws were placed and countersunk across the fracture fragment. The articulating surface with the navicular is evaluated visually to assess congruency, and the subtalar joint is checked for residual loose bodies (Fig. 4). Wound is closed in layers. The

Fig. 4 Intraoperative imaging. (a) AP and (b) lateral showing reduced fracture held in place with two headless screws in a reduced subtalar joint



patient is then placed in a short-leg non-weight-bearing cast for a total of 6–8 weeks and then transitioned to CAM boot with weight-bearing and range-of-motion exercises for an additional 4 weeks. This is followed by slow introduction of activities at 3 months and physical therapy for stiffness and monthly follow-up for the first 3 months (Fig. 5) and then every 2–3 months for progress. Last follow-up was at 1 year (Fig. 6).

However, talar fractures are probably best classified according to the age of the child, with children younger than 6 years having a better prognosis than older children. Treatment of talar fractures in younger children is more often conservative with casting and overall good outcomes. In contrast, these fractures in older children are best addressed as talar fractures in adults.

5 Basic Principles

One of the basic principles when discussing talar fractures is the blood supply. This can be compromised after a displaced talar neck or body fracture with subsequent development of avascular necrosis (AVN). There are four main sources of blood supply and are branches of the posterior tibial, anterior tibial, and peroneal arteries. Letts and Gibeault proposed a classification for pediatric talar fractures, which is useful in determining prognosis in terms of development of osteonecrosis:

- Type I. Minimally displaced fracture of the distal talar neck (the incidence osteonecrosis is low)
- Type II. Minimally displaced fracture of the proximal neck or body (the risk osteonecrosis is low with this type also)
- Type III. Displaced talar neck or body fracture (osteonecrosis is more likely)
- Type IV. Talar neck fracture with dislocation of the body fragment (osteonecrosis is expected in these type of fracture-dislocations)

6 Images During Treatment

See Figs. 4 and 5.

7 Technical Pearls

In general, the management of minimally displaced, <2 mm, or minimally angulated fractures, <5°, on the AP view is closed reduction and casting with non-weight-bearing restrictions. In order to reverse the mechanism of injury, the foot is positioned in slight plantarflexion. This treatment is continued until there is evidence of fracture healing which is usually between 6 and 8 weeks. At that time patient can then be transitioned to a weight-bearing cast for an additional 4–6 weeks. Open reduction and internal fixation is required for displaced fractures. Anteromedial approach to talus is utilized and preferred for fracture fragment reduction. Depending on the fracture pattern, Kirschner wire or cannulated screws can be placed anterior to posterior or retrograde in order to maintain reduction. Lag screws are

Fig. 5 Radiographs at 1-month postoperative visit. (a) AP, (b) lateral, and (c) oblique showing maintained alignment of the fracture and well-placed screws transfixing the fracture



preferred as they provide better fixation with less displacement than seen with smooth wires. Fixation is followed by cast immobilization and non-weight bearing until union is accomplished.

A fracture through the body of the talus is much less common than talar neck fractures in both adults and children and generally carries a worse prognosis, especially when the fracture is displaced.

If the fracture cannot be initially determined on radiographs or if there is an initial subtalar dislocation, a post-reduction CT is important to rule out fracture or intra-articular fragments that will not be clearly defined in radiographs. In the very young children, it is also possible that the partially ossified talus may be less likely to be fractured. In this case a bone scan may be indicated to identify the talar fracture.

Due to potential complications of these fractures, follow-up is important. Radiographic assessment for the Hawkins sign should be performed between 6 and 8 weeks after injury. The Hawkins sign, described as a radiolucency in the subchondral area, indicates that the body of the talus has not undergone an avascular process. If the Hawkins sign is present, the likelihood the talar body has a good blood supply and will remain viable is high. In this case, the patient can then begin bearing weight. If by 3 months post injury there is no radiographic indication of the Hawkins sign, an MRI is indicated. Keep this in mind with fractures that need surgical

fixation and use titanium implants to allow for clearer visualization.

8 Outcome Clinical Photos and Radiographs

See Fig. 6.

9 Avoiding and Managing Problems

Talar fractures occur more commonly and with more severity in older children. As in adults, nearly 50% of the fractures occur in the talar neck. High-energy talar fractures in children are frequently associated with other traumatic injuries. Post-traumatic complications after pediatric talar fractures occur more frequently after a high-energy mechanism of injury or displaced fracture. In younger children alternate imaging may be required for proper diagnosis. CT scan is helpful for diagnosis in older children or in those fractures with associated subtalar dislocations. Displaced fractures require open reduction and internal fixation. Smooth wires or cannulated screws are utilized. Titanium implants are preferred. In the follow-up period, watch out for the

Fig. 6 One-year follow-up radiographs. (a) AP, (b) lateral, and (c) oblique. Healed fracture. No evidence of avascular necrosis or post-traumatic arthrosis



Hawkins sign and if concerned obtain an MRI. Even with non-displaced fractures, disclose the potential for post-traumatic complications to the patient on initial encounter.

10 Cross-References

► Isolated Lateral Malleolus Fracture

References and Suggested Readings

- Herring JA (2014) Tachdjian's pediatric orthopaedics: from the Texas Scottish Rite Hospital for Children, vol 2, 5th edn. Elsevier, Philadelphia
- Lovell WW, Winter RB, Weinstein SL, Flynn JM (2014) Lovell and Winter's pediatric orthopaedics, vol 2, 7th edn. Lippincott Williams & Wilkins, Philadelphia
- Smith JT, Curtis TA, Spencer S, Kasser JR, Mahan ST (2010) Complications of talus fractures in children. *J Pediatr Orthop* 30:779–784

Calcaneus Fracture in Children

M. Pierce Ebaugh and Christopher A. Iobst

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Abstract

Pediatric calcaneus fractures are rare with reported incidences of 1 in 100,000 (Beaty JH, Kasser JR, Rockwood and Wilkins' fractures in children. Lippincott Williams & Wilkins, Philadelphia, 2010). The majority of calcaneus fractures in children under 14 are extra-articular. However, high energy adult like fractures are known to occur in adolescents (Beaty JH, Kasser JR, Rockwood and Wilkins' fractures in children. Lippincott Williams & Wilkins, Philadelphia, 2010). After falling out of a second story window, a 15-year-old male sustained a joint depression type calcaneus fracture. He was placed

into a bulky posterior splint in the emergency department and then underwent open reduction internal fixation at 14 days post injury utilizing an extensile lateral approach. Subsequently, he achieved fracture union without complication and progressed to full weight bearing at 8 weeks.

1 Brief Clinical History

A 15-year-old male fell out of a second story window while playing the guitar, landing on both feet. He sustained a left closed foot injury without neurovascular compromise. Due to his fall from height, he also sustained vertebral compression fractures at T12, L1, L2, and L4. His foot was placed into a bulky splint in the emergency department and scheduled for outpatient follow-up. Prior to leaving the emergency department, a CT scan was obtained.

The patient followed up in the clinic 9 days later. After reviewing the CT scan, he was determined to have a Sanders IIa type calcaneus fracture. Treatment options were discussed with the family and operative intervention was elected. His

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Fig. 1 Bohler's Angle is shown in white. Angle of Gissane is shown in red

soft tissue envelope was examined. The amount of swelling and ecchymosis was deemed to be safe for surgery and he was consequently scheduled for fixation at 14 days after injury.

2 Preoperative Imaging

Standard anteroposterior and lateral foot views were obtained. On the lateral view (Fig. 1), the clinician should evaluate the posterior facet congruity, Bohler's Angle (20–40°), and the Angle of Gissane (120–145°). A Harris Axial view of the calcaneus should also be obtained to visualize the body, tuberosity, and sustentaculum (Fig. 7). Broden's view gives an excellent view of the posterior facet. This radiograph is obtained with 40° of internal rotation and between 15° and 40° cephalad tilt (Beaty and Kasser 2010). CT has now become standard of care to classify intra-articular fractures and to plan for operative intervention (Table 1) (Sanders et al. 1993).

3 Preoperative Problem List

1. The calcaneus fracture was associated with high-energy vertebral body compression fractures. While the fractures are stable, this must be taken into account during positioning of the patient in the operating room.
2. Risk factors associated with poor outcomes in adults are uncommon in pediatric patients (diabetes, smoking, alcohol abuse, and work-related injury).
3. The patient has a displaced joint depression type calcaneus fracture which is best treated with reduction of the posterior facet and restoration of length and alignment.

Table 1 Sanders Classification

Type I	Nondisplaced posterior facet (regardless of number of fracture lines)
Type II	One fracture line in the posterior facet (two fragments)
Type III	Two fracture lines in the posterior facet (three fragments)
Type IV	Comminuted with more than three fracture lines in the posterior facet (four or more fragments)

A-lateral portion of facet, B-central portion of facet, C-medial portion of facet

Table 2 Schmidt Classification

Type I	(A) Fracture of tuberosity of apophysis (B) Fracture of sustentaculum tali (C) Fracture of anterior process (D) Distal inferolateral aspect (E) Small avulsions off body
Type 2	(A) Beak fracture (B) Avulsion fracture of insertion of Achilles tendon
Type 3	Linear fracture not involving subtalar joint
Type 4	Linear fracture involving subtalar joint
Type 5	(A) Tongue type (B) Joint-depression type
Type 6	Significant bone loss of posterior aspect with loss of Achilles tendon insertion

4 Treatment Strategy

Fractures of the calcaneus most often occur due to a fall from height, but may also occur from high-energy events such as a motor vehicle accident (Beaty and Kasser 2010). Traditionally, management of calcaneal fractures in children has been nonoperative, owing to the large percentage of these fractures being extra-articular, low energy, and in immature patients, creating favorable results for healing (Mora et al. 2001; Brunet 2000). This has been attributed to theories of the immature talus remodeling to an incongruous subtalar joint (Mora et al. 2001; Brunet 2000). However, comminuted, displaced intra-articular fractures in the nearly skeletally mature should be addressed with operative intervention as in adults (Summers et al. 2009). Careful evaluation of patient and fracture pattern is the most important step in the treatment of pediatric calcaneus fractures.

Analysis of the fracture pattern starts with classification via radiographs and CT scanning. The Schmidt classification of children's calcaneal fractures is currently the most commonly used system and incorporates the traditional Essex Lopresti classification (Table 2) (Beaty and Kasser 2010). The Sanders classification is based on findings from the CT and should be used for adolescent fractures (Table 1) (Beaty and Kasser 2010; Sanders et al. 1993). Following classification, management decisions can be made.

Proper management of the pediatric calcaneus fracture begins in the emergency department. Due to fall being a

common mechanism of injury, calcaneus fractures are frequently associated with vertebral fractures, with incidences approaching 10% in adults and 5% in children (Beaty and Kasser 2010). Careful evaluation of the spine should accompany any physical exam of patients with calcaneal fractures. Tongue type calcaneus fractures, should also be given special attention due to the high incidence of skin compromise over the posterior tuberosity. Gardner et al. examined 127 tongue type calcaneus fractures over 5 years and found a 21% incidence of skin compromise (Gardner et al. 2008). This constitutes a surgical urgency to prevent soft tissue envelope compromise and necrosis.

The decision to proceed with surgical intervention of calcaneus fractures can be challenging. Currently, there is no consensus due to the rarity of these fractures in children. The management is mostly based on anecdotal evidence with exclusive nonoperative management in young children and adolescents being managed as adults. However, it is generally accepted that adolescents with displaced intra-articular calcaneus fractures (Sanders II, III, IV) should be treated operatively (Buckley et al. 2002; Howard et al. 2003). This is partially due to the fact that adolescents are believed to lack the remodeling potential of younger children (Mora et al. 2001; Brunet 2000). Also, adolescents usually fall into the favorable prognostic categories of nonsmokers without Worker's compensation claims. Those with extra-articular fractures and nondisplaced intra-articular fractures without skin compromise can be managed nonoperatively (Beaty and Kasser 2010). Tongue type fractures can be managed nonoperatively if intra-articularly it is non displaced, the tuberosity displacement is less than 1 cm, the Achilles is not significantly shortened, and there is no posterior skin compromise (Beaty and Kasser 2010).

Nonoperative treatment involves placing the foot into a boot, with very-well-padded posterior slab splint or cast along with strict elevation. Extra-articular fractures can be managed with 6 weeks of non-weight-bearing in children with progression to weight-bearing in a boot. The majority of calcanei should be splinted or casted in neutral dorsiflexion, but tongue type fractures should be immobilized in slight equinus to prevent the gastrocnemius-soleus complex from further displacing the fracture. Sanders type 1 fractures treated nonoperatively should remain non-weight-bearing for approximately 3 months but transition to a boot should begin at 6 weeks for range of motion exercises (Sanders 2000).

Operative intervention should be undertaken within 3 weeks, specifically prior to fracture consolidation (Sanders 2000). Surgical planning begins with controlling swelling. The operative calcaneus should be placed into a very-well-padded posterior slab splint in neutral dorsiflexion with specific instructions of non-weight-bearing and elevation. Alternatively, the patient can be taken



Fig. 2 Lateral radiograph of the foot displays a joint depression type calcaneus fracture

upon presentation to the operating room for medially based external fixation. This can help with those not amenable to percutaneous fixation, those with Bohler's angle of <5 (significant height loss), or fracture dislocations. It also creates a platform and works as a reduction tool during definitive fixation. The soft tissue envelope is considered acceptable for incision when there is no pitting edema and it wrinkles with foot dorsiflexion and eversion (Sanders 2000). This may take anywhere from 10 to 14 days.

Our patient was evaluated in the emergency department and noted to have multiple vertebral body compression fractures. The calcaneus fracture was closed, and there were no radiographic or clinical signs of skin tenting. Examination of his radiographs revealed an adult type intra-articular joint depression type calcaneus fracture (Fig. 2). He was placed into a posterior slab with sugar tong stirrup lower leg splint with generous amounts of padding. Prior to discharge, a CT scan was obtained for preoperative planning.

Nine days later, he followed up in the clinic. Classification of the fracture pattern on CT scan was consistent with a Sanders IIA (Figs. 3, 4, 5). The patient and his family elected to proceed with operative intervention. The splint was taken down to examine the skin, it was determined that the patient needed several more days of strict elevation before the soft tissues would be amenable to an incision.

5 Basic Principles

1. Following initial radiographic analysis and physical exam, the patient should be placed into a very-well-padded posterior slab splint or taken to the operating room for external fixation.
2. After immobilization, if radiographic findings suggest an intra-articular fracture pattern, a CT scan should be obtained for fracture analysis.



Fig. 3 Coronal CT scan cut

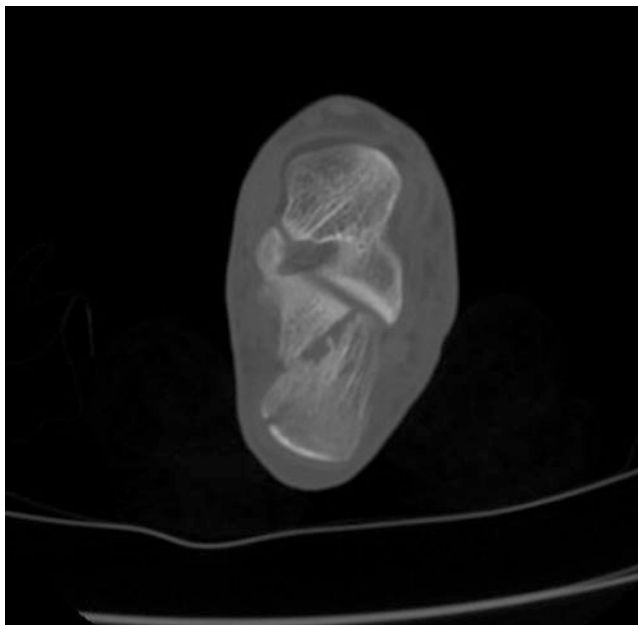


Fig. 4 Axial CT scan cut

3. Evaluation of the CT determines the need for operative versus nonoperative treatment. If operative treatment is chosen, the CT scan helps with surgical planning.
4. Definitive fixation should only be attempted with an amenable soft tissue envelope. In the interim, the patient should remain non-weight-bearing with strict elevation to control swelling. Operative intervention should be performed as soon as the soft tissue allows to avoid callus formation, making reduction difficult.

6 Technical Pearls

Positioning The patient is placed in the lateral decubitus position with the operative hip free, so the limb may be



Fig. 5 Sagittal CT scan cut

rotated for fluoroscopic views. A tourniquet is placed on the thigh. The nonoperative hip is flexed and the knee slightly flexed while the operative hip is slightly extended and knee flexed to 90° and placed on a large elevated radiolucent pad. This allows for an operative platform and keeps the other extremity out of fluoroscopic views.

Approach: Extensile Lateral The vertical limb of the incision is made 1 cm anterior to the Achilles tendon beginning at the level of the tip of the distal fibula down to the glabrous border of the plantar foot. The incision then gently curves into the horizontal limb which extends to the base of the fifth metatarsal along the glabrous border. The lateral flap is a full-thickness dissection, with the anterior portion being elevated in subperiosteal fashion. The calcaneofibular ligament is elevated and the peroneal tendons, sural nerve, and lateral calcaneal artery are included in the flap. 0.062 K wires are inserted into the fibula, talus, and fifth metatarsal then bent to create a no touch technique for flap retraction (Gardner and Henley 2010). Gentle handling of the soft tissues and a tensionless closure are essential to help prevent wound-healing issues. **Combined Sinus Tarsi and Medial:** For the sinus tarsi, a 4–6 cm incision is made paralleling the plantar surface of the foot just anterior and distal to the fibula. Care is taken to avoid the peroneal tendons. The medial incision is made over the tuberosity with two finger breadths posterior to the medial malleolus. Care must be taken to avoid the medial calcaneal branches of the tibial nerve. Laterally, an arthroscope can be used to aid in posterior facet reduction (Carr 2005).

Reduction: Medial External Fixation Half pins are placed into the distal tibia, tuberosity, and medially in the cuneiforms. The reduction progresses in the following sequence: height, length, varus, and translation. A distractor can facilitate the reduction process.

Tongue Type and Tuberosity Avulsion Fractures: A Schanz pin is placed posterior to anterior into the tuberosity to disimpact and reduce it. A sinus tarsi approach evaluates the subtalar joint. K wires are then placed posterolateral to the tuberosity.

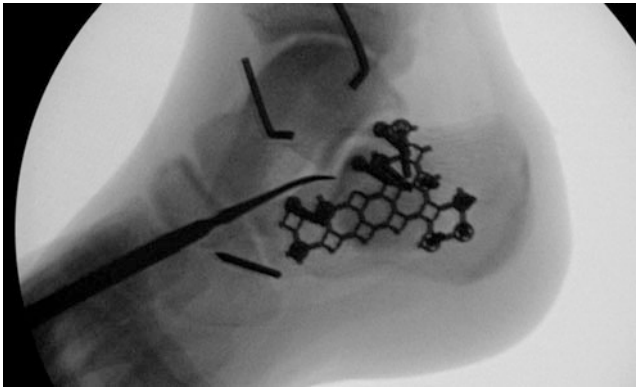


Fig. 6 Intraoperative radiograph of posterior facet reduction process

anteroinferior to secure the reduction. Cannulated 3.5 mm screws are placed over the wires.

Joint Depression Fractures: Following the approach, the lateral wall is removed. A Schanz pin is then inserted lateral to medial into the tuberosity as a reduction aid with the following motion: posterior–inferior, medial translation, and valgus rotation. Fragment reduction proceeds in the following order: anterior process to superomedial (constant) fragment, constant fragment to tuberosity, posterior facet to constant fragment, and replacement of lateral wall (Gardner and Henley 2010; Carr 2005). Fragments are initially held with K wires then secured with anatomic plates and small fragment screws.

Post Op Management Immobilization in a splint or cast is essential. Sutures may be left in for up to 3 weeks to minimize wound healing issues. After wound healing, range of motion exercises can begin. Non-weight-bearing is continued for 9 weeks post operatively (Sanders 2000).

After placing our patient into the lateral decubitus position using a bean bag positioner, the operative leg was placed on a radiolucent bolster to create a sturdy surgical platform. An extensile lateral incision was performed with a full thickness flap elevated. Subperiosteal dissection continued; we elected to use the no touch technique placing pins into the fibula, talus, and cuboid. The lateral wall was removed and the posterior facet was addressed first with elevation and lag screws. The tuberosity was taken out of varus using the aforementioned joystick technique and the sustentaculum elevated and fixed positionally. Satisfied with the overall reduction, autograft from the crushed tuberosity was replaced and augmented with calcium phosphate. The lateral wall was replaced and a large mesh plate placed in a lag type fashion to compress the lateral wall (Fig. 6). A drain was placed and taken out of the field proximally. Allgower-Donati technique sutures were used to close the wound and the patient was placed into a posterior slab splint with sugar tong stirrup. The

patient was admitted overnight for observation. The patient returned to the office at 1 week for a wound check; sutures were maintained. Sutures were then removed at 3 weeks post operatively to ensure adequate wound healing and decreased dehiscence. At that point, the patient can be transitioned into a walker boot, but should remain non-weight-bearing until 9 weeks.

7 Clinical Outcomes/Imaging

Historically, nonoperative treatment has been the mainstay for pediatric calcaneus fractures. Brunet followed 19 non-operatively treated calcaneus fractures (15 intra-articular and 4 extra-articular) for an average of 16.8 years following injury and had an average AOFAS score of 96 (out of 100) with only two cases of post traumatic arthritis (Brunet 2000). However, 17 of the 19 were under the age of 10. Inokuchi reported on 20 calcaneus fractures, 18 of which were treated nonoperatively and 17 of the 18 had good outcomes. Once again the average age was preadolescent at 8.4 years (Inokuchi et al. 1998).

Review of operatively treated pediatric calcaneus fractures centers around the adolescent with an open distal tibial physis and usually a greatly displaced avulsion type or intra-articular fracture. Pickle et al. operatively treated six displaced intra-articular fractures in children 11 years or older without any postoperative complications. All were pain free and back to activities at 10 months, but five patients had decreased subtalar motion (Pickle et al. 2004). Petit et al. operatively treated 14 displaced intra-articular fractures; only one patient was under the age of 10. The average AOFAS hindfoot score was 64 out of 68 possible points and only three patients suffered minor complications (Petit et al. 2007).

Final radiographs of our patient demonstrate restoration of Bohler's and Gissane's angles along with appropriate length and alignment of the tuberosity (Figs. 7 and 8).

8 Avoiding and Managing Problems

Wound issues are the main concern of operatively treated calcaneus fractures. These issues are often seen in poorly controlled diabetes, smokers, and morbidly obese patients. Layered closure and immobilization until incision healing is essential in preventing problems (Beaty and Kasser 2010).

Complex regional pain syndrome, also known as reflex sympathetic dystrophy, can be a more common occurrence in the lower extremity in children. It is more commonly found in adolescent girls. Management utilizing a multidisciplinary approach at a tertiary care children's hospital is the optimal method of treatment (Beaty and Kasser 2010).



Fig. 7 Post operative Harris Heel Axial radiograph

Peroneal tendonitis and dislocation can occur in both nonoperatively and operatively treated calcaneal fractures. In nonoperative patients, a displaced lateral wall and/or sub-fibular impingement can cause tendon irritation. In operatively treated patients, it is usually due to irritation from hardware. In all cases, corticosteroid injection and immobilization are helpful, followed by removal of the offending agent as a last resort (Beaty and Kasser 2010).

References

- Bajammal S, Tornetta P, Sanders D, Bhandari M (2005) Displaced intra-articular calcaneal fractures. *J Orthop Trauma* 19(5):360–364
- Beaty JH, Kasser JR (2010) Rockwood and Wilkins' fractures in children. Lippincott Williams & Wilkins, Philadelphia
- Brunet JA (2000) Calcaneal fractures in children. Long-term results of treatment. *J Bone Joint Surg Br* 82(2):211–216
- Buckley R, Tough S, McCormack R et al (2002) Operative compared with nonoperative treatment of displaced intra-articular calcaneal



Fig. 8 Post operative Lateral Foot radiograph

- fractures: a prospective, randomized, controlled multicenter trial. *J Bone Joint Surg Am* 84-A(10):1733–1744
- Carr JB (2005) Surgical treatment of intra-articular calcaneal fractures: a review of small incision approaches. *J Orthop Trauma* 19(2):109–117
- Gardner MJ, Henley MB (2010) Harborview illustrated tips and tricks in fracture surgery. Lippincott Williams & Wilkins, Philadelphia
- Gardner MJ, Nork SE, Barei DP, Kramer PA, Sangeorzan BJ, Benirschke SK (2008) Secondary soft tissue compromise in tongue-type calcaneus fractures. *J Orthop Trauma* 22(7):439–445
- Howard JL, Buckley R, McCormack R et al (2003) Complications following management of displaced intra-articular calcaneal fractures: a prospective randomized trial comparing open reduction internal fixation with nonoperative management. *J Orthop Trauma* 17(4):241–249
- Inokuchi S, Usami N, Hiraishi E, Hashimoto T (1998) Calcaneal fractures in children. *J Pediatr Orthop* 18(4):469–474
- Mora S, Thordarson DB, Zions LE, Reynolds RA (2001) Pediatric calcaneal fractures. *Foot Ankle Int* 22(6):471–477
- Petit CJ, Lee BM, Kasser JR, Kocher MS (2007) Operative treatment of intraarticular calcaneal fractures in the pediatric population. *J Pediatr Orthop* 27(8):856–862
- Pickle A, Benaroch TE, Guy P, Harvey EJ (2004) Clinical outcome of pediatric calcaneal fractures treated with open reduction and internal fixation. *J Pediatr Orthop* 24(2):178–180
- Sanders R (2000) Displaced intra-articular fractures of the calcaneus. *J Bone Joint Surg Am* 82(2):225–250
- Sanders R, Fortin P, Dipasquale T, Walling A (1993) Operative treatment in 120 displaced intraarticular calcaneal fractures. Results using a prognostic computed tomography scan classification. *Clin Orthop Relat Res* 290:87–95
- Summers H, Ann Kramer P, Benirschke SK (2009) Pediatric calcaneal fractures. *Orthop Rev (Pavia)* 1(1):e9

Pediatric Lisfranc

Kerry L. Loveland and Kimberly Grannis

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Abstract

Historically, Lisfranc or tarsometatarsal fractures were seen mostly in adults and rarely in the pediatric population. With more detailed imaging techniques such as magnetic resonance imaging (MRI) and a higher suspicion for

injury, these fractures are now being seen more commonly in children, especially athletes. Generally, patients do well with nonoperative treatment and a period of nonweight bearing and cast immobilization. For significantly displaced injuries, closed reduction should be attempted and open reduction internal fixation or percutaneous pinning undertaken if the injury continues to be unstable. Anatomical restoration is the key for expected overall good outcomes.

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1 Brief Clinical History

Thirteen-year-old male was moving a stack of pallets to help a puppy when the pallets fell onto his left foot. He sustained an isolated injury to his left foot.

The tarsometatarsal joint (TMT) is comprised of the base of metatarsals one through five and their articulations with the medial, middle, lateral cuneiform, and the cuboid. It separates the midfoot from the forefoot. The joint is named after a French surgeon and gynecologist, Jacques Lisfranc, who described amputations through that joint in 1815 while working in the Napoleonic Army (Cassebaum 1963). Transverse stability of this joint is based on the key-stone formation of wedge-shaped metatarsal bases and their corresponding cuneiform-cuboid articulations. The second metatarsal is unique in that it is recessed for additional support. Stability in this area is provided by ligamentous support, most notably from the Lisfranc ligament. The Lisfranc ligament runs from the medial cuneiform to the second metatarsal. It has dorsal, plantar, and interosseous segments with the plantar side being the strongest leading the dorsal side to rupture first.

The term “Lisfranc injury” refers to any injury where the metatarsals are displaced from the tarsus and can be purely ligamentous or involve osseous and articular structures. It more commonly refers to injuries involving the 2nd tarsometatarsal joint (Desmond and Chou 2006).

2 Epidemiology

Lisfranc injuries in the adult population are rare accounting for only 0.2% of all fractures (Mantas and Burks 1994) and even more uncommon in children. The mechanism of injury has been described as the “bunk bed” fracture complex (GF 1981) as a fall from heights with forceful plantarflexion of the foot with axial loading or a direct crush injury. Approximately 60% of these injuries are fall from height with males affected more than females (JJ 1981) (GF 1981). Nearly 20% of these injuries are missed or misdiagnosed upon initial radiographic imaging and clinical evaluation; however, with advanced imaging techniques using CT and MRI, a higher number of diagnosis are made today (Trevino 1995).

3 Anatomy

The tarsometatarsal joint anatomy is complicated and involves a combination of nine bones with their corresponding ligaments. The complex osseous relationships provide an intrinsic stability of the transverse arch of the foot. The trapezoidal shape of the base of metatarsals 3–5 forms a Roman arch (Goossens and DeStoop 1983). As with all

Roman arches, a keystone is necessary to maintain the structure. In the foot, the keystone is the second tarsometatarsal joint. The recessed position of the middle cuneiform allows the trapezoidal shape of the base of the second metatarsal to articulate with five structures simultaneously (1st/3rd metatarsals and all three cuneiforms) locking the arch in position. The importance of this recessed anatomy was demonstrated by Peicha et al. who showed that individuals who sustained a Lisfranc injury had a shallower recessed middle cuneiform than population norms (Peicha et al. 2002).

While we commonly describe the entire ligamentous complex of the tarsometatarsal joint as the “Lisfranc” joint, that is not an accurate description of the location of the Lisfranc ligament. There are strong transverse ligaments which connect the base of the 2–5 metatarsals, but this ligament is not found between the first and second metatarsal bases. Instead, a strong ligament extends from the medial cuneiform to the base of the second metatarsal. This ligament is composed of three components: dorsal, interosseous, and plantar ligaments. The plantar ligaments are the strongest. This is the true “Lisfranc” ligament and is the strongest structure supporting the tarsometatarsal joint (Solan et al. 2001).

The neurovascular bundle composed of the dorsalis pedis artery and deep peroneal nerve course dorsally to the cuneiforms. They then separate in the interosseous space of the 1st and 2nd metatarsals as the artery courses plantarward and becomes the plantar arterial branch and the nerve continues distally to give sensation to the first web space. The close relationship of this bundle with the medial TMT joint must be remembered as it can be injured with the trauma or during operative fixation of the injury. Tendinous attachments also help provide stability to the midfoot and arch. The anterior tibialis tendon inserts at the base of the 1st metatarsal and medial cuneiform dorsally, and the peroneus longus tendon inserts opposite of this on the plantar surface. The relationship of these two muscle attachments gives added dynamic stability to the medial arch.

4 Preoperative Clinical Photos and Radiographs

See Fig. 1.

5 Preoperative Problem List

1. Widening of space between base of 1st and second metatarsal
2. Elevation of base of 2nd metatarsal in relation to middle cuneiform (as seen on lateral radiograph)
3. Fracture of base of 5th metatarsal

Fig. 1 13-year-old male injured left foot. **(a)** Lateral foot x-ray showing elevation of 2nd metatarsal in relation to middle cuneiform. **(b)** AP foot x-ray showing widening of 1st-2nd metatarsal bases. **(c)** Oblique foot x-rays showing base of 5th metatarsal fracture with maintained alignment of 4th metatarsal with cuboid



6 Treatment Strategy

1. Need to restore base of second metatarsal into its position as “keystone” of arch of foot either via closed or open reduction
2. Stabilize base of second metatarsal in position so tarsometatarsal ligaments (including Lisfranc ligament) can scar back into position of function
3. Stabilize base of other metatarsals to assure arch of foot is maintained
4. Use fixation which respects open growth plates
5. Optional: stabilize fracture of base of 5th metatarsal

7 Diagnosis

Patients often present with pain, edema, and tenderness over the Lisfranc joint. Plantar ecchymosis in conjunction with axial load/fall from height mechanism of injury is highly suggestive of a Lisfranc injury (Ross 1996).

Radiographic evaluation using the normal relationships of the second tarsometatarsal joint in the pediatric population can prove to be more difficult given their incomplete ossification. AP, lateral, and oblique views should be taken for initial evaluation with images taken parallel to the midfoot joints. Placing the patient prone for posterior-anterior views of the midfoot can increase the visualization of these joints. For more subtle injuries, weight-bearing views can aid in the diagnosis. These can prove difficult secondary to pain; therefore, a stress view in abduction may reveal subtle instability,

especially at the first TMT joint (Coss 1998). On AP views, the medial aspect of the base of the second metatarsal should align with the medial aspect of the middle cuneiform. An oblique film shows alignment of the medial border of the fourth metatarsal and medial border of the cuboid (the lateral column). On lateral films, the dorsal and plantar cortex of the metatarsals should be congruent with the cuneiforms and cuboid.

The second TMT joint may be dorsally subluxed with rupture of the Lisfranc ligament, best seen on the lateral view (Coss 1998). Although less commonly seen in the pediatric population, an isolated fracture at the base of the second metatarsal or medial cuneiform should raise high suspicion for an avulsion of the Lisfranc ligament otherwise known as the “fleck sign” (Myerson 1986). The distance between the bases of the first and second metatarsal should not exceed 2–3 mm (Tadros 2008; Potter 1998). Comparison radiographs of the uninjured foot may aid in unrecognized ligamentous injury as slight dorsal subluxation is more difficult to appreciate in the pediatric population (GF 1981).

8 Classification

The classification used most widely today was described by Hardcastle et al. (JBJS 1982) based off of the classification developed by Quenu and Kuss in 1909 (Quenu 1909). Further classification systems which further subdivide types B and C of Hardcastle’s classification (Myerson 1986) or base it upon clinical presentation and symptoms (Nunley and Vertullo 2002) also exist.

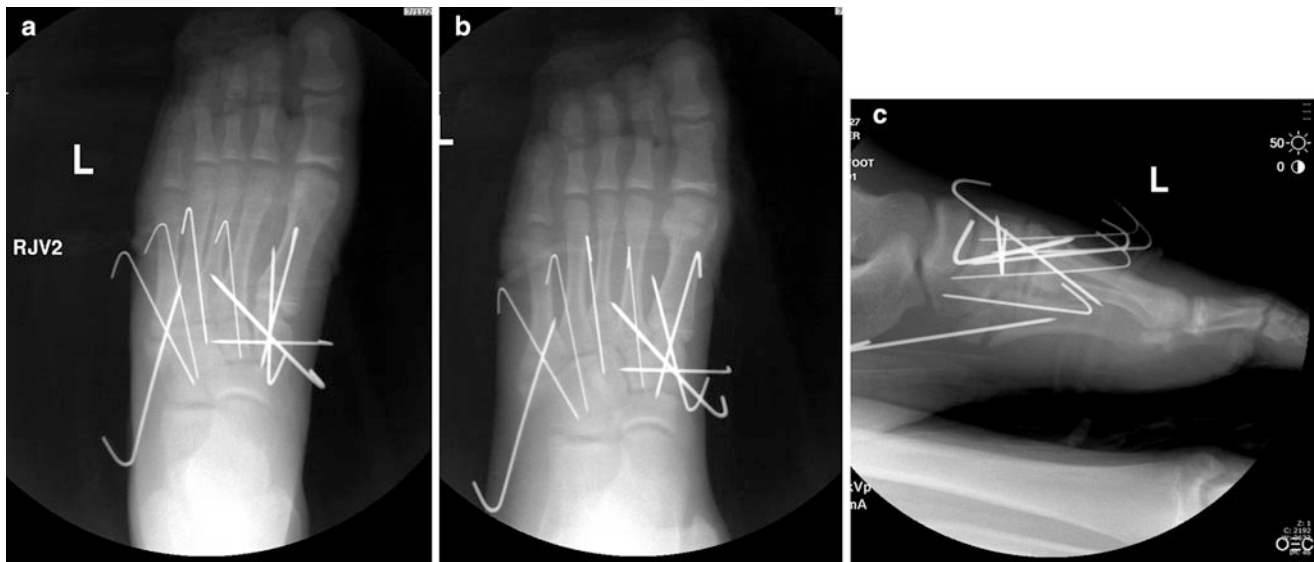


Fig. 2 Intraoperative fluoroscopy images showing ORIF of base of all metatarsals. (a) AP. (b) Oblique. (c) Lateral. Note near anatomic alignment of base of all metatarsals and use of smooth pins to respect growth plates

Type A: This category describes total incongruity of the TMT joint. The dislocation can be in either in the coronal or sagittal plane or a combination of these, but the key feature is the entire TMT joint is dislocated. The original description of “homolateral” dislocation would’ve fall into this category.

Type B: Partial incongruity is the main feature for these injuries. It is either a medial dislocation of only the first metatarsal either through a fracture at the base of the metatarsal or a dislocation at the 1st TMT joint or it is lateral displacement of metatarsals 2–5 laterally.

Type C: This category describes a divergent pattern. It is medial displacement of the first metatarsal with some combination of lateral displacement of metatarsals 2–5. It can be a total incongruity or a partial incongruity pattern, but the key distinguishing feature is that there is a combination of both medial and lateral displacement of some sort.

Fortunately, most children’s injuries are a type B injury with minimal displacement. Type A and C injuries are rare in general and even less common in children (Wiley 1981). Nunley’s description of athletic injuries is helpful as their treatment algorithm led to excellent results in 93% of patients (Nunley and Vertullo 2002).

9 Basic Principles

9.1 Management

The number one priority is being certain to understand the full extent of injury that has occurred. Second is to assure that anatomic alignment of the TMT joint is accomplished.

Nondisplaced fractures where anatomic alignment is maintained on a nonweight bearing x-ray require treatment with a below knee cast for 4–6 weeks. Weight bearing can be advanced between 4 and 6 weeks postinjury. Return to full activity should be avoided until 3–4 months postinjury.

Wiley reported that nearly 40% of patients require closed reduction and that closed reduction must be maintained with internal fixation. Finger traps are a helpful adjunct for reduction. Fortunately, open reduction is rarely needed in the pediatric/adolescent population. However, open reduction may be necessary to remove interposing tissue to allow for reduction and restoration of anatomic alignment. For the pediatric population, fixation is most commonly achieved with K-wires, but in skeletally mature adolescents, cannulated screw fixation is preferred for fixation of metatarsal joints 1–3. Screw fixation is preferred in this older patient population as it must be left in position longer and k-wires will loosen and/or break necessitating earlier than desired removal. Screw placement is from the base of the first metatarsal to the medial cuneiform and from the medial cuneiform to the base of the second metatarsal. Fixation of the base of the 4–5th TMT joint should almost always be done with K-wires where possible due the need for these joints to have more mobility once the healing has completed. Timing of hardware removal is between 3 and 4 weeks for 4–5th metatarsal bases (k-wires). Screw removal from the medial joints can be done once painless weight bearing is achieved. Leaving the screws longer than 3 months risks long-term joint damage and screw breakage (Stavalas 2010).

Children who are suspected to have a high energy Lisfranc injury should be admitted overnight for observation given the concern for significant soft tissue injury leading to



Fig. 3 Follow-up radiographs after pins have been removed and weight bearing resumed. (a) AP weight bearing. (b) Oblique weight bearing. (c) Lateral weight bearing. Note maintained alignment of Lisfranc joint

compartment syndrome. Children with a low energy sporting injury typically do not require admission. If the patient is young, they may have difficulty expressing pain and symptoms so surgeons should have a low threshold for compartment syndrome and operative intervention (Wallin 2016). A fasciotomy of all nine compartments of the foot should be performed if clinical suspicion is high or compartment pressures are greater than 30 mm Hg (Kay 2001; Manoli 1990).

10 Images During Treatment

See Fig. 2.

11 Technical Pearls

When performing this procedure, an adequate bump is necessary to obtain AP/oblique/lateral x-rays without having to move the foot significantly. A large bump extending under the full length of the leg is helpful in achieving this. If reduction cannot be obtained closed, a 2-incision technique with incisions centered over 1st/2nd metatarsal space and 3rd/4th metatarsal space over the tarsometatarsal joints can be utilized. Reduction begins with base of 1st metatarsal to medial cuneiform and then between medial and middle cuneiforms. This provides a stable base to reduce the base of the 2nd metatarsal. Once it is anatomicallly reduced, it can be fixated to the medial and middle cuneiforms. Reduction of remaining TMT joints progresses towards the lateral side of the foot until entire TMT joint is well secured. For skeletally

immature patients, use 0.062 smooth k-wires to minimize physeal damage. Pins remain until the 6th week and are removed in clinic. Patient is casted and remains nonweight bearing for a total of 12 weeks.

12 Outcome Clinical Photos and Radiographs

See Fig. 3.

13 Avoiding and Managing Problems

The most common complication of a Lisfranc injury is chronic pain. This is most commonly from posttraumatic arthritis but can also be from complex regional pain syndrome. Hardcastle et al. and Myerson et al. both demonstrated type B injuries to have the worse outcomes, but upon closer examination this is likely because a partial incongruity injury can often go undiagnosed for prolonged periods of time and presentation beyond 6 weeks is associated with worse outcomes (Hardcastle 1982; Myerson 1986). Wiley showed 78% good to excellent outcomes in his pediatric population of 18 patients none of whom required open reduction. Of the four patients that were not pain free at 1 year follow-up, three of them had not had anatomic reduction and one presented late and was thus never treated. This again demonstrates the key to treatment is anatomic realignment (Wiley 1981). Treatment of complex regional pain syndrome is conservative with physical therapy and possibly referral to

a pain specialist. Treatment of pain from posttraumatic arthritis is more complicated and involves conservative treatment with orthotics and PT. If those measures fail, the salvage procedure is an arthrodesis of the involved joints.

Avoidance of early complications primarily involves treatment of pin tract infections and skin slough. Do not place the patients in a cast immediate postoperatively. After the initial postoperative evaluation at 7–10 days after surgery, a cast can be placed. They should return at 6 weeks post op for pin removal and cast change. Pin tract infections can usually be managed with oral antibiotics and leaving the pins in place until the 6th week.

14 Cross-References

- [Base of Fifth Metatarsal Fracture](#)
- [Foot Compartment Syndrome](#)

References and Suggested Readings

- Cassebaum W (1963) Lisfranc fracture-dislocations. *Clin Orthop* 30:116–128
- Coss HM (1998) Abduction stress and AP weightbearing radiography of purely ligamentous injury in the tarsometatarsal joint. *Foot Ankle Int* 19(8):537–541
- Desmond EA, Chou L (2006) Current Concepts review: Lisfranc injures. *Foot Ankle Int* 27(8):653–660
- Goossens M, DeStoop N (1983) Lisfranc's fracture-dislocations: etiology, radiology, and results of treatment. *Clin Orthop Relat Res* 176:154–162
- Hardcastle PR-L (1982) Injuries to the tarsometatarsal joint: incidence, classification and treatment. *J Bone Joint Surg Br* 64(3):349–356
- Johnson G (1981) Pediatric Lisfranc Injury: "bunk bed" fracture. *AJR Am J Roentgenol* 137:1041–1044
- Kay RT (2001) Pediatric foot fractures: evaluation and treatment. *J Am Acad Orthop Surg* 9:308–319
- Kay R, Tang C (2001) Pediatric foot fractures: evaluation and management. *J Am Acad Orthop Surg* 9:308–319
- Manoli AW (1990) Fasciotomy of the foot: an anatomical study with special reference to release of the calcaneal compartment. *Foot Ankle* 10:267–275
- Mantas JP, Burks R (1994) Lisfranc injuries in the athlete. *Clin Sports Med* 13(4):719–730
- Myerson MF (1986) Fracture dislocations of the tarsometatarsal joints: end results correlated with pathology and treatment. *Foot Ankle* 6(5):225–242
- Nunley JA, Vertullo CJ (2002) Classification, investigation, and management of midfoot sprains: Lisfranc injuries in the athlete. *Am J Sports Med* 30:871
- Peicha G, Labovitz J, Seibert FJ, Grechenig W, Weiglein A, Preidler KW, Quehenbreger F (2002) The anatomy of the joint as a risk factor for Lisfranc dislocation and fracture-dislocation: an anatomical and radiological case control study. *J Bone Joint Surg Br* 84:981–985
- Potter HD (1998) Magnetic resonance imaging of the Lisfranc ligament of the foot. *Foot Ankle Int* 19:438–446
- Quenu EK (1909) Etude sur les luxations du metatarses (luxations metatarsotarsiennes) du diastasis entre le 1er et le 2 metatarsien. *Rev Chir* 39:281
- Ross GC (1996) Plantar ecchymosis sign: a clinical aid to diagnosis of occult Lisfranc tarsometatarsal injuries. *J Orthop Trauma* 10(2):119–122
- Solan MC, Moorman CT 3rd, Miyamoto RG, et al. (2001) Ligamentous restraints of the second tarsometatarsal joint: a biomechanical evaluation. *Foot Ankle Int* 22:637
- Stavalas PR (2010) The role of reduction and internal fixation of Lisfranc fracture-dislocations: a systematic review of the literature. *Int Orthop* 34(8):1083–1091
- Tadros A, Al-Hussona M (2008) Bilateral tarsometatarsal fracture-dislocations: a missed work-related injury. *Singap Med J* 49(9):e234–e235
- Trevino SK (1995) Controversies in tarsometatarsal injuries. *Orthop Clin North Am* 26(2):229–238
- Wallin K (2016) Acute traumatic compartment syndrome in the pediatric foot: a systemic review and case report. *J Foot Ankle Surg* 55:817–820
- Watson T, Shurnas P, Denker J (2010) Treatment of Lisfranc joint injury: current concepts. *J Am Acad Orthop Surg* 18:718–728
- Wiley J (1981) Tarso-metatarsal joint injuries in children. *J Pediatr Orthop* 1:255

Base of Fifth Metatarsal Fracture

Monica Payares-Lizano

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Abstract

Metatarsal bone fractures account for more than half of all pediatric foot fractures and 15% of all injuries of the foot. Fortunately, the vast majority of these fractures can be treated conservatively with immobilization alone. Metatarsal fractures generally result from direct trauma such as a heavy object falling on the foot or a crush injury in a motor vehicle accident or from indirect trauma such as a twisting injury. Metatarsal neck fractures are more often caused by a torsional force applied to the foot, whereas direct compression results in shaft fractures. Open reduction with internal fixation is indicated for patients with open fractures, irreducible fractures, and those that cannot maintain reduction by casting.

Fractures of the base of the fifth metatarsal are best classified according to their anatomical location which are divided into three zones of the proximal metatarsal.

Zone I comprises the cancellous tuberosity, including the insertion of the peroneus brevis tendon and the calcaneometatarsal ligament of the plantar fascia. Zone II is the distal aspect of the tuberosity with dorsal and plantar ligamentous attachments to the fourth metatarsal. Zone III begins distal to the ligamentous attachments and extends to the mid-diaphyseal area. It is important to recognize a zone II injury, the Jones fracture, which is prone to non-union because of the watershed area of blood supply in this region. Surgical treatment of acute Jones fractures has been advocated for active and athletic adolescents to avoid issues associated with delayed healing.

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1 Brief Clinical History

This 12-year-old female sustained a fall down a set of stairs twisting her left foot approximately 2 weeks prior to presentation. She was seen at an outside institution and placed on a short leg cast. On initial evaluation, radiographs showed an avulsion fracture of the base of the fifth metatarsal (Fig. 1). In the oblique view, the alignment appears anatomic; however, on AP view the fracture is displaced and thus a CT scan was done in order to better characterize this fracture. The CT scan revealed a displaced base of the fifth metatarsal fracture with the articular surface rotated (Fig. 2). She was indicated for open reduction and internal fixation due to fracture displacement and loss of articular congruency.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Displaced fragment (>2 mm)
2. Rotated fracture fragment with disruption of articular congruency
3. Chronicity of the fracture (>2 weeks)
4. Fixation options to be guided by the size of fragment

4 Treatment Strategy

In this case, the fragment was not only displaced more than 2 mm but also rotated 180° so that the base of the fifth metatarsal was no longer articulating with the cuboid and thus open reduction was warranted. The size of the fragment is also important as it may not even hold a small diameter screw. In that case, a smooth pin or suture anchor can be used as an alternative. In an acute fracture, you may find a small amount of fracture hematoma and possible interposed soft tissue. In this case, there was already early callus formation which prevented anatomic reduction and thus curettes and rongeurs were used to evacuate the hematoma and remove any callus or soft tissue interposed within



Fig. 1 Preoperative anteroposterior (AP) (a), lateral (b) and oblique (c) radiographs. Avulsion fracture of the base of the fifth metatarsal. On the oblique view, the alignment appears anatomic however on the AP view it looks displaced and on the lateral view it is difficult to assess the alignment

fracture fragment. For your reduction maneuvers, one must keep in mind of deforming forces including the lateral band of the plantar aponeurosis and peroneus brevis attachment. Once reduced, the guide pin for the 3 mm cannulated screw was placed across the fracture site, maintaining anatomic reduction. The cannulated reamer was placed over the guide pin. Pointed reduction clamps may be used to hold fragment and prevent rotation. The appropriate length screw was placed across the fracture site, achieving compression across the fracture. Postoperatively, the patient was immobilized in a short leg nonweight bearing cast for 6 weeks and then transitioned to hard sole shoe and progressive weight bearing.

Fig. 2 CT Images preoperative – (a) coronal, (b) sagittal, (c) axial, (d) 3D-reconstruction sagittal. Displaced base of the fifth metatarsal fracture with the articular surface rotated 180° and no longer articulating with the cuboid

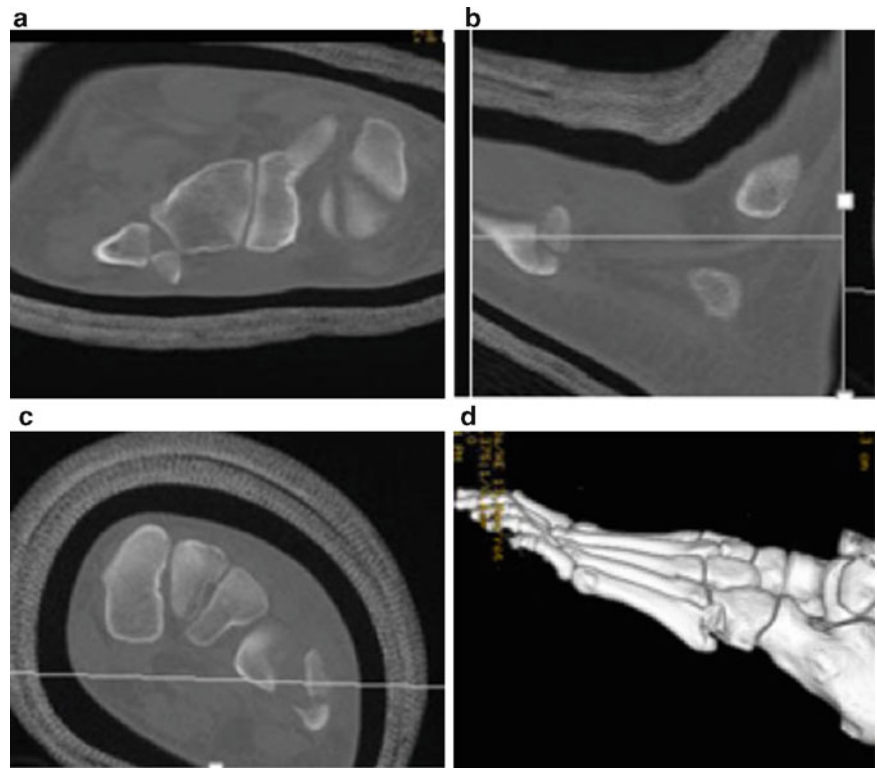
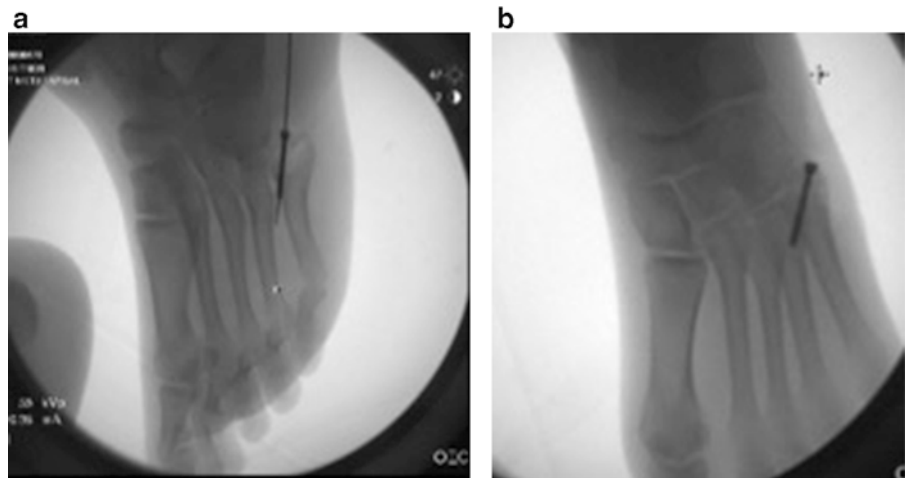


Fig. 3 Intraoperative images (a) cannulated screw over guide wire with reduced fracture. (b) AP view showing reduced fracture and well-placed bicortical screw transfixing the fracture in its anatomic position



5 Basic Principles

Basic principles for the management of this type of fracture include: *restoration of anatomic alignment, articular congruency, absolute stability of fixation, and preservation of blood supply and soft tissues.*

It has been suggested in cadaveric studies that the lateral band of the plantar aponeurosis tethers the fifth metatarsal to create avulsion fractures of the tuberosity with the peroneus brevis tendon as the major deforming force contributing to further displacement. Displaced fractures (>2 mm) and particularly those that enter the cuboid–fifth metatarsal joint may be treated with primary internal fixation using a tension band

Fig. 4 Two weeks postoperative AP (a) and lateral (b) radiographs showing interval healing of the fracture and proper positioning of the screw holding in fracture in anatomical alignment

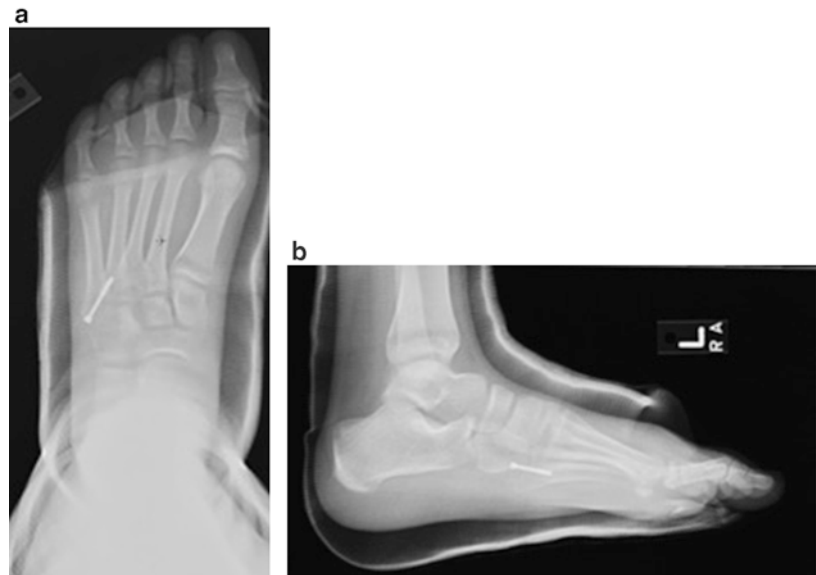


Fig. 5 Three months postoperative AP (a), lateral (b) and oblique (c) radiographs. Showing threaded bone screw through the base of the fifth metatarsal through a healed fracture. No malalignment or loosening or screw cut out

construct or lag screw. These will provide the absolute stability needed for articular fractures and is achieved by interfragmentary compression.

As with any fracture, it is important to preserve blood supply, being careful not to devascularize the fragment during the approach and reduction maneuvers. Soft tissues should be handled with care.

6 Images During Treatment

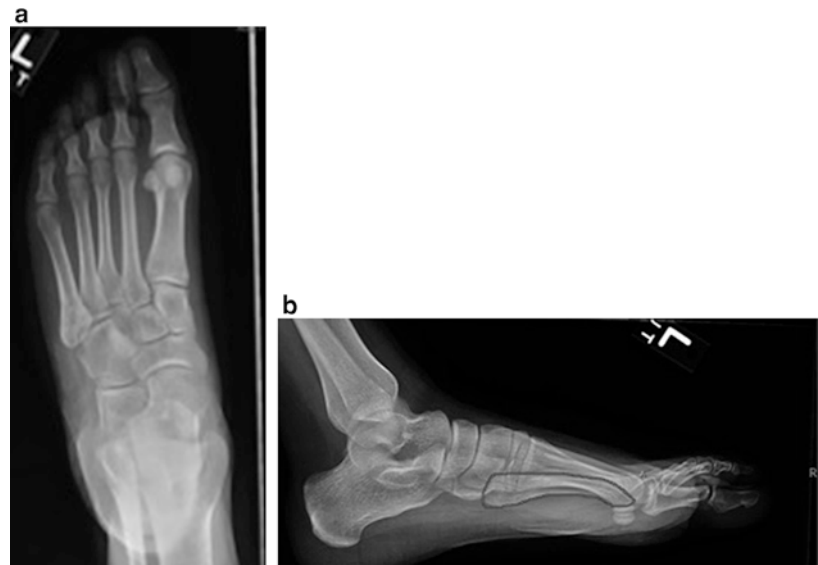
See Figs. 3 and 4.

7 Technical Pearls

Minimally displaced fractures are amenable to percutaneous technique with closed reduction and use of partially threaded screws to compress across the fracture. In cases where there is further displacement or rotation, or those more chronic in nature will more likely require open reduction. Be careful not to devoid the fragment of all soft tissue attachments even though some soft tissue may be required to allow reduction. This will prevent devascularization of the fragment and possibly a delayed union or nonunion.

For reduction, you may use pointed reduction clamps but be careful not to crush the fracture fragment. If small enough, using a small bone hook or dental pick and then pinning in place may be a better option. You may not need to over drill over the guide pin. Use the small bone hook or dental pick as you insert the screw to prevent the fragment from spinning at the same time providing more rotational control.

Fig. 6 AP (a) and lateral (b) views after hardware removal at 7 months. Showing healed fracture and restored anatomic alignment



With smaller fragments or if screw fixation failed, consider using suture anchors. Be careful not to leave the screw's head too prominent as to prevent hardware irritation in this very superficial area.

radiographic healing lags behind clinical healing in the nonoperatively treated fracture. Remember this when deciding to clear patients for return to full activities.

8 Outcome Clinical Photos and Radiographs

See Figs. 5 and 6.

9 Avoiding and Managing Problems

Carefully review all views of radiographs, if there is any doubt, obtain a CT for better assessment and decision making. If nonoperative management is decided, follow radiographically and clinically. It may take 6–8 weeks to heal completely. If surgical fixation is indicated, anatomic reduction is key to minimize long term issues. If open reduction is required, protect your soft tissues. Handle fragments with care if fracture fragment is too small or breaks through, consider suture anchors. Also keep in mind that

10 Cross-References

► [Intra-articular Phalanx Fracture of Great Toe](#)

References and Suggested Readings

- Herrera-Soto JA, Scherb MDM, Duffy MDMF et al (2007) Fractures of the fifth metatarsal in children and adolescents. *Pediatr Orthop* 27(4):427–431
- Herring JA (ed) (2014) Tachdjian's pediatric orthopaedics: from the Texas Scottish Rite Hospital for children, 5th edn. Elsevier, Saunders
- Lovell WW, Winter RB, Weinstein SL, Flynn JM (2014) Lovell and Winter's pediatric orthopaedics, vol 2, 7th edn. Lippincott Williams & Wilkins, Philadelphia. Print
- Singer G, Cichocki MDM, Schalamon MDJ et al (2008) A study of metatarsal fractures in children. *Bone Joint Surg Am* 90(4):772–776



Pediatric Metatarsal Fractures

Ross Smith and Daniel Grant

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Abstract

The pediatric foot is different from an adult foot in that the bones begin largely as cartilaginous and vary in time to ossification. This requires a different approach to the management of pediatric foot fractures. The remodeling potential in the pediatric foot allows some displacement and angulation of fractures to be acceptable in children that would not be acceptable in adults. Fracture recognition can be difficult due to ossification centers and growth plates. Of fractures in the pediatric foot, metatarsal fractures are the most common. Often trauma to the pediatric metatarsals can be treated nonoperatively due to the remodeling potential of the bones and their tolerance of displacement, which typically results in good functional

results. Only severely displaced or open metatarsal fractures require operative treatment.

1 Brief Clinical History

A 15-year-old male hit his right foot on a stair while jumping into a pool. He complained of significant pain and deformity of his right foot. He was splinted at an outside facility that recommended follow-up with an orthopedic surgeon. He presented to our clinic 4 days out from his initial injury. He was using crutches and had been elevating his foot. His right foot was significantly swollen and had no skin wrinkling. He described subjective paresthesias throughout his toes. Brisk capillary refill was present in all toes. The posterior tibial artery and dorsalis pedis artery pulses were palpable.

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Fig. 1 Preoperative AP, radiograph



Fig. 2 Preoperative, oblique, radiograph

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

Right first closed displaced comminuted metatarsal fracture with extension into the tarsometatarsal (TMT) joint, second closed displaced comminuted metatarsal neck fracture, third closed displaced comminuted metatarsal neck fracture, fourth closed minimally displaced metatarsal neck fracture (Figs. 1, 2, and 3).

4 Treatment Strategy

Options for treatment of metatarsal fractures include non-operative casting, external fixation, open reduction with internal fixation, and closed reduction and pinning. Open

reduction with internal fixation was selected due to the comminuted and displaced nature of the first, second, and third metatarsals. Operative intervention was delayed for a week to allow the swelling to subside. The instability of the axial alignment of the fractures would not allow for pinning to maintain an acceptable length and alignment. Open reduction with internal fixation provided the opportunity to achieve stability in the intraarticular first metatarsal fracture and the axially unstable metatarsal fractures.

5 Basic Principles

Principles of treatment include careful handling of the soft tissues, anatomic reduction of the fractures, and maintaining the reduction with implants. An incision was made over the first metatarsal on the dorsal medial aspect of the foot to allow access to the first metatarsal and the first tarsal-metatarsal joint. The joint stability between the first metatarsal and medial cuneiform as well as the medial and medial cuneiform were assessed under direct visualization and noted

Fig. 3 Preoperative lateral radiograph



Fig. 4 Fluoroscopic image of the contralateral foot for comparison



Fig. 5 Provisional reduction of the first metatarsal with Kirschner wire (K-wire) holding the reduction

to be stable. The first metatarsal was pinned out to length which assisted with the reduction (Fig. 5). The intra-articular fragment was then reduced and held in place with a lag screw. Due to the extensive comminution, a bridge plate construct was used to maintain the alignment of the first metatarsal with the goal of obtaining indirect bone healing. The second and third metatarsals were noted to be extensively comminuted and shortened compared to the opposite foot (Figs. 4 and 5). Due to the axially instability, the decision was made to plate the second and third metatarsals instead of performing a closed reduction and pinning. An incision was made between the second and third metatarsals to allow access of both

metatarsals. Again due to the comminution, bridge plate constructs were used (Figs. 6, 7, and 8). The incisions were closed. The patient was instructed to keep the foot elevated for several days postoperatively to help prevent wound breakdown due to swelling. Weight-bearing was allowed at 6 weeks once callous formation was noted around the fractures. By 4 months postoperatively, he was returning to sports. At 1 year from surgery, the fractures have healed well (Figs. 9, 10, 11, 12, and 13). He remains active and is having no pain. Unless the hardware becomes bothersome, it will be left in place.



Fig. 6 Fluoroscopic image AP



Fig. 8 Fluoroscopic image lateral



Fig. 7 Fluoroscopic image, oblique



Fig. 9 One year clinical radiograph



Fig. 10 One year clinical radiograph



Fig. 11 One year follow-up radiographs: AP



Fig. 12 One year follow-up radiographs: oblique

6 Images During Treatment

See Figs. 4, 5, 6, 7, and 8.

7 Technical Pearls

- Avoid incisions on skin that is too swollen. Wait for skin wrinkles to return before surgery.
- Obtain images of the contralateral foot. In comminuted fractures, this can help guide restoration of the metatarsal cascade.
- Utilize K-wires to hold the fractures reduced. Pin to other metatarsals as needed.
- Metatarsal fractures can be challenging to align and pin closed. If necessary, make an incision to aid with the reduction, even when pinning metatarsal fracture.

Fig. 13 One year follow-up radiographs: lateral



- Make sure the incisions are spread as far as possible to avoid flap necrosis (often the 6 cm ideal spread is not obtainable).
- For multiple axially unstable fractures, consider plating instead of pinning.
- Reduce and stabilize the intra-articular fragment followed by the metaphyseal/diaphyseal fragments.

8 Outcome Clinical Photos and Radiographs

See Figs. 9, 10, 11, 12, and 13.

9 Avoiding and Managing Problems

Common problems with surgery of the foot and ankle include infection, wound complications, and hardware prominence or failure. Concerns specific to this population include growth disturbance due to physal trauma and patient compliance. Perioperative antibiotics are routinely used to decrease the risk for surgical site infection. Specific considerations to avoid wound complications include waiting for wrinkling of the skin prior to surgery and care when handling soft tissues in the operating room. Hardware prominence is a common problem

with plating and can often necessitate removal. Growth disturbance is a consideration with all fractures involving or adjacent to open growth plates. Careful hardware placement to avoid the physis when possible is the best way to lower the risk of this complication. Nonunions are rare in the pediatric population however soft tissue stripping and infection can lead to this complication. Careful preoperative planning, using appropriate fixation constructs, and applying knowledge of fracture healing biomechanics are necessary to obtain acceptable outcomes.

10 Cross-References

- [Base of Fifth Metatarsal Fracture](#)
- [Foot Compartment Syndrome](#)

References and Suggested Reading

- Beaty J, Kasser J (2010) Rockwood and Wilkins' fractures in children, 7th edn. Lippincott Williams & Wilkins, Philadelphia, pp 1044–1045
- Green S (2008) Skeletal trauma in children, 4th edn. Saunders, Philadelphia, pp 552–559
- Morrissy R, Weinstein S (2014) Lovell and Winter's pediatric orthopaedics, 7th edn. Lippincott Williams & Wilkins, Philadelphia, pp 1822–1824

Intra-articular Phalanx Fracture of Great Toe

Maegen Wallace and L. Reid Nichols

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Abstract

Phalanx fractures of the toes are fairly rare injuries in children. Treatment of most of these injuries is non-operative with symptomatic treatment. A common treatment regimen is weight-bearing as tolerated often in a stiff-soled shoe until the patient is comfortable ambulating in their regular shoes. A case series of hallux fractures found that soccer was the most common mechanism and 86% of children were treated non-operatively (Petnehazy et al. *Foot Ankle Int* 36:60–63, 2015). Displaced intra-articular fractures in older children can be treated often with closed reduction, open reduction if needed, and percutaneous pin or screw stabilization for

4–6 weeks. Reduction is recommended if the great toe proximal phalanx joint surface is displaced more than 2–3 mm or 25% of the joint surface is involved. Most of these fractures are Salter-Harris III or IV injuries. A case series with four gymnasts with Salter-Harris (SH) III and IV injuries that all underwent open reduction and pin fixation with good outcomes has also been described (Perugia et al. *Injury* 45(Suppl 6):S39–S42, 2014). Another case series with ten patients published in 2014 (Kramer et al. *J Pediatr Orthop* 34:144–149, 2014) found most patients required open reduction through a dorsal approach to the MTP joint and often found a periosteal flap of tissue in the physis which prevented a successful closed reduction. They also found progressive intra-articular displacement both preoperatively and postoperatively and recommend close radiographic follow-up of these fractures.

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1 Brief Clinical History

A 13-year-old, high-level gymnast presents to the emergency department with a great toe injury. She was splinted and told to follow up in the orthopedic clinic. Follow-up radiographs showed a displaced intra-articular fracture of the great toe. She had injured this toe 2 years prior, and there was significant swelling at the initial injury. Radiographs demonstrated a displaced intra-articular proximal phalanx fracture, with some sclerosis which may have occurred at the previous injury. The toe was very swollen; therefore the case was scheduled in 2 days with instructions for strict elevation.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Fracture of left great toe with significant displacement involving >25% of articular surface in a high-level gymnast.

2. Swelling of great toe. Surgery was scheduled for 2 days post injury with hopes that swelling would decrease with splinting and elevation.
3. Consideration of surgical approach – dorsal or lateral.
4. Method of fixation. Open reduction and internal fixation using K-wires or screws.

4 Treatment Strategy

A discussion on the pros and cons of both non-operative and operative treatment should be had with the patient and family. Complications of operative treatment are reported to be as high as 60% with loss of reduction, nonunion, avascular necrosis, and posttraumatic arthritis being the most common (Kramer et al. 2014). A study that reviewed proximal phalanx great toe fractures found that fractures involving the lateral condyle had a high risk of symptomatic nonunion and recommended more aggressive treatment of these injuries with surgery (Park et al. 2013). Complications of non-operative treatment for non-displaced fractures are minimal with 14% complaining of mild pain and 5% with a decreased range of motion (Petnehazy et al. 2015).



Fig. 1 (a) Preoperative AP radiograph of the left foot demonstrating displaced intra-articular fracture of the proximal phalanx of the great toe. (b) Preoperative lateral radiograph of the left foot demonstrating

displaced intra-articular fracture of the proximal phalanx of the great toe. (c) Preoperative sesamoid view of the great toe looking for direction of displacement of fracture fragment

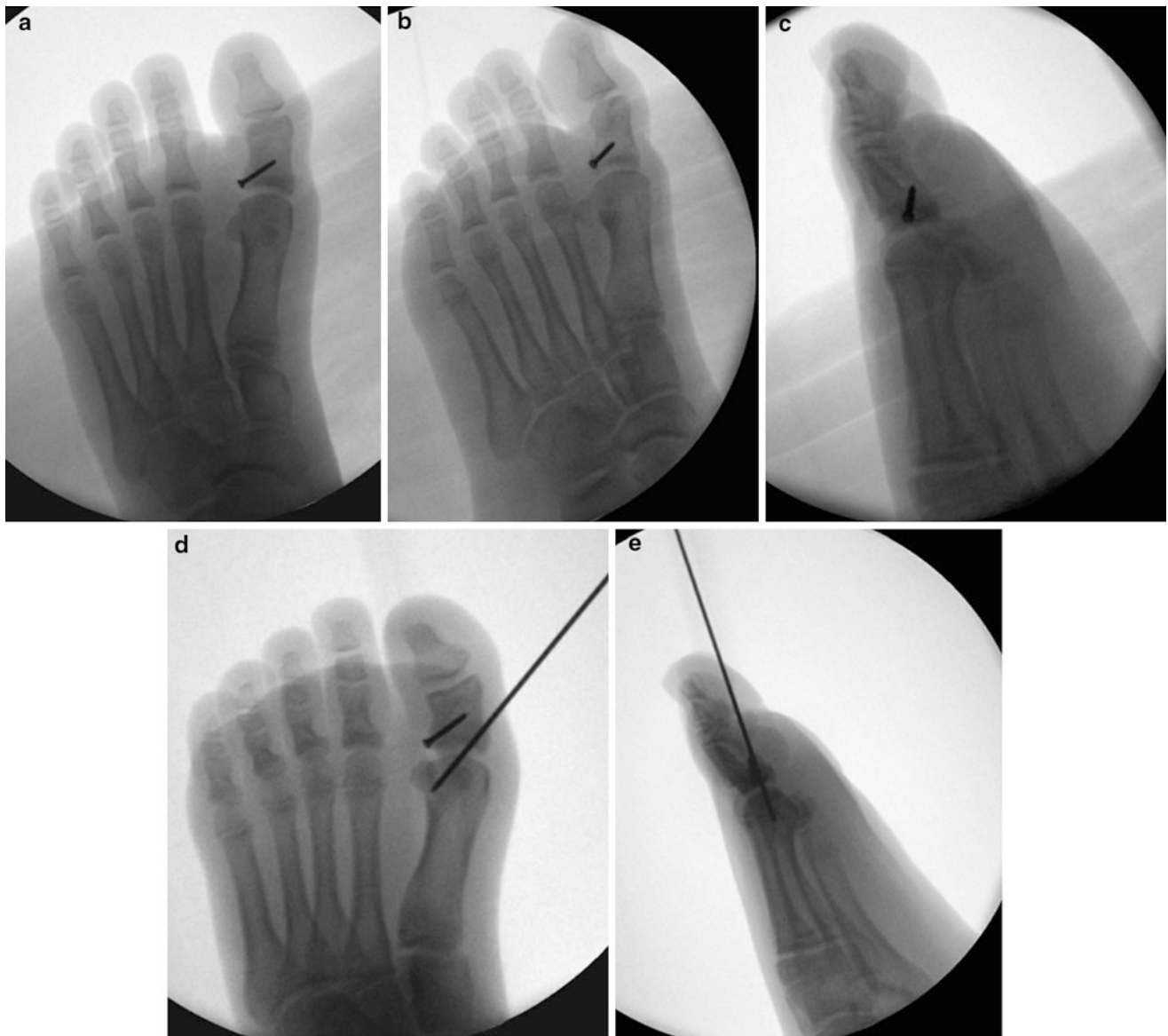


Fig. 2 (a) Intraoperative AP of the proximal phalanx of the great toe. (b) Intraoperative oblique of the proximal phalanx of the great toe. (c) Intraoperative lateral of the proximal phalanx

of the great toe. (d) Intraoperative AP of the proximal phalanx of the great toe with fixation of MTPJ. (e) Intraoperative lateral of the proximal phalanx of the great toe with fixation of the MTPJ

5 Basic Principles

The goals of treating intra-articular fractures are to obtain and maintain joint congruency in order to decrease posttraumatic arthritis of the joint and avoid nonunion. Current recommendations of intra-articular fractures of the great toe are to consider operative management if $>25\%$ of the articular surface is involved or if there is >2 mm of displacement (Petnehazy et al. 2015). Operative treatment includes an attempt at closed reduction, which often fails, followed by open reduction.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

The recommended operative approach is through a dorsal or dorsolateral longitudinal (Perugia et al. 2014) incision with care taken to avoid deep plantar

dissection in the first web space to decrease the incidence of avascular necrosis. Fixation options include K-wires, crossing the physis as needed, mini fragment screws and possibly suture anchors. K-wires have been known to migrate either if they are buried or left outside the skin. The use of mini fragment screws may be difficult depending on the trajectory and may result in additional soft tissue dissection which can lead to blood supply issues to small fragments of bone.

8 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

9 Avoiding and Managing Problems

Problems may be avoided by selecting the right patients and fractures to treat operatively. Operative treatment requires close follow-up as loss of reduction,

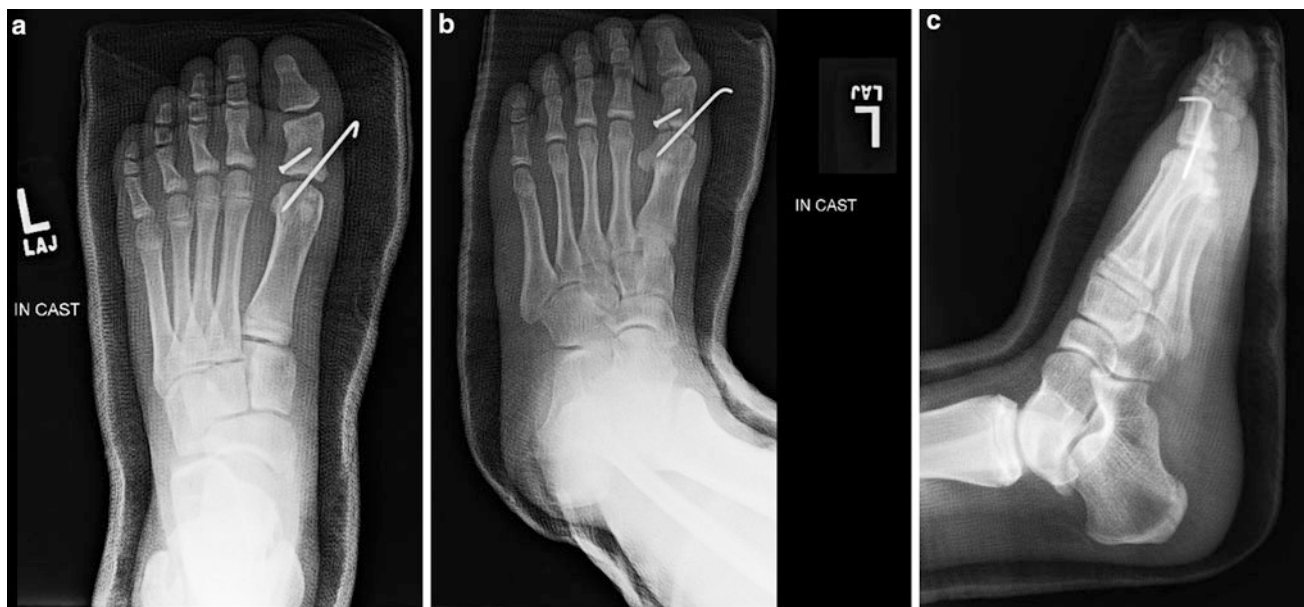


Fig. 3 (a) Postoperative AP of the proximal phalanx of the great toe with fixation of MTPJ. (b) Postoperative oblique of the proximal phalanx of the great toe with fixation of MTPJ. (c) Postoperative lateral of the proximal phalanx of the great toe with fixation of MTPJ



Fig. 4 (a) Healing AP of great toe. (b) Healing oblique of great toe. (c) Healing lateral of great toe

infection, and avascular necrosis of small fracture fragments can occur. Non-operative or operative management can result in degenerative changes to the joint and hallux rigidus which can be treated with shoe wear modification and ultimately a fusion of the affected joint (Kramer et al. 2014). Nonunions can occur as well and can successfully be

treated with open reduction and fixation (Bariteau et al. 2015).

The bony fragment is often small and in an anatomically challenging location. The following is an example of a lateral fragment which was reduced and displaced during healing period. The patient was pain-free at pin removal (Fig. 5).



Fig. 5 (a) Initial displacement of right great toe. (b) Postoperative fixation of right great toe. (c) Postoperative fixation of right great toe. (d) AP radiograph of the healing fracture demonstrating displacement of the fracture fragment. (e) Oblique radiograph of the healing fracture

demonstrating displacement of the fracture fragment. (f) Lateral radiograph of the healing fracture demonstrating displacement of the fracture fragment

References and Suggested Readings

- Bariteau JT, Murillo DM, Tenenbaum SA et al (2015) Joint salvage after neglected intra-articular physeal fracture of the hallux in high-level gymnasts. *Foot Ankle Spec* 8:130–134
- Kramer DE, Mahan ST, Hresko MT (2014) Displaced intra-articular fractures of the great toe in children: intervene with caution! *J Pediatr Orthop* 34:144–149
- Park DY, Han KJ, Han SH et al (2013) Barefoot stubbing injuries to the great toe in children: a new classification by injury mechanism. *J Orthop Trauma* 27:651–655
- Perugia D, Fabbri M, Guidi M et al (2014) Salter-Harris type III and IV displaced fracture of the hallux in young gymnasts: a series of four cases at 1-year follow-up. *Injury* 45(Suppl 6):S39–S42
- Petnehazy T, Schalamon J, Hartwig C et al (2015) Fractures of the hallux in children. *Foot Ankle Int* 36:60–63

Foot Compartment Syndrome

Maegen Wallace and L. Reid Nichols

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Abstract

Compartment syndrome of the foot can occur with severe soft tissue injuries to the foot, with or without fractures in the foot. With significant trauma, especially crush injuries with fractures Bibbo et al. (*Pediatr Emerg Care* 16:244–248, 2000) to the foot, one must have a high index of suspicion for compartment syndrome. If compartment syndrome is suspected, some authors recommend measuring compartment pressures in the operating room or under sedation, while others are skeptical of the validity of compartment pressure measurements in the foot. These authors recommend taking the patient directly to the operating room to release the compart-

ments. The most sensitive compartment to measure is reported to be the calcaneal compartment. All nine compartments should be released if the decision is to proceed to surgical decompression. There is some controversy about the outcomes of compartment syndrome release being worse than the natural history of nonoperative treatment of foot compartment syndrome, and some authors no longer recommend foot compartment releases.

1 Brief Clinical History

A 12-year-old boy was struck by a car while crossing the street on his bike. He was not helmeted and was thrown into the median. He sustained a left femoral shaft fracture, severe crush injury to the right foot, orbital fractures, depressed skull fracture with intraparenchymal bleed, and a severe concussion.

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Fig. 1 (a) Right foot AP radiograph demonstrating comminution and shortening of first metatarsal and comminuted fractures of the medial and middle cuneiforms. (b) Right ankle lateral demonstrating substantial comminution of the calcaneus



Fig. 2 (a) CT scan of right foot shows medial malleolus fracture and medial, middle, and lateral cuneiform fractures. (b) CT scan of right foot illustrates the extent of bone loss and comminution of the anterior calcaneus. (c) CT scan, 3D Reconstruction of right foot. (d) CT scan, 3D Reconstruction of right foot

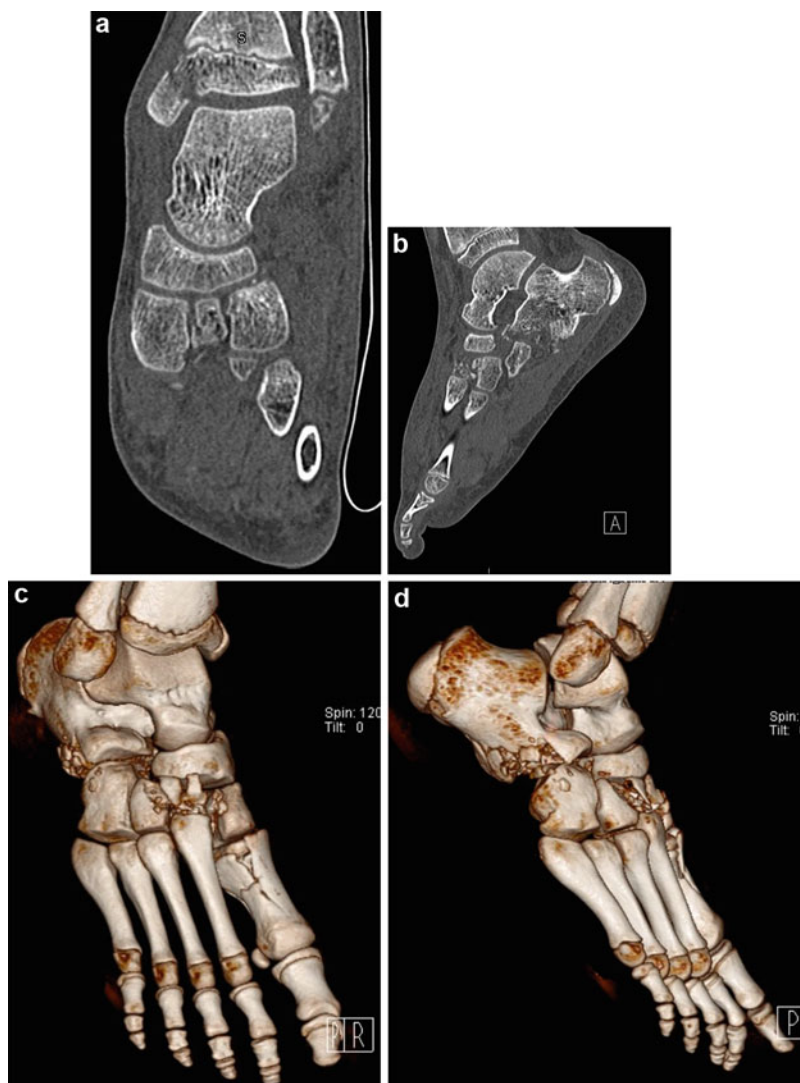


Fig. 3 (a) Left femur AP. Long spiral femoral shaft fracture. (b) Left femur lateral showing displacement and mild shortening of the femoral shaft



2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List (Outline Format)

1. Clinical examination: Multiple fractures with concomitant major head trauma. Neurosurgery would not allow prolonged surgical intervention. The neurosurgeon allowed the patient to go to the operating room after second CT scan of the head was unchanged from the initial admission. Per the neurosurgeon's recommendation, the femur fracture and contralateral foot injuries needed to be stabilized within 1 h of anesthesia time in the operating room. The foot was of great concern due to the extent of soft tissue and bony injury. Frequent neurovascular exams were performed on the floor after the foot and femur were provisionally splinted. Pressures were not measured on the floor. He has normal sensation in the superficial and deep peroneal nerves. Motor was limited secondary to pain.
2. Femur fracture management. Damage control was goal because of the extent of injuries and time constraints. An external fixator was placed temporarily with the plan of a submuscular plate when patient stability improved.
3. Foot fracture management. Damage control must be goal secondary to neurologic injury.
 - (a) Mildly displaced oblique fracture of the medial aspect of the distal right tibial epiphysis extending into the distal right tibial physis, compatible with a Salter-Harris III fracture.
 - (b) Comminuted fracture of the calcaneus, particularly involving the middle and anterior talar articular surfaces.
 - (c) Minimally displaced fracture at the medial superior aspect of the medial cuneiform.
 - (d) Comminuted fracture of the first metatarsal involving the proximal metatarsal physis.
 - (e) Multiple osseous fragments at the articulation between the medial cuneiform and the first metatarsal. The intermediate cuneiform is extensively comminuted with the base of the second metatarsal displaced proximally.
 - (f) Comminuted fracture of the medial and proximal aspects of the lateral.
 - (g) Disruption in the articulation between the anterior aspect of the calcaneus and the cuboid with multiple osseous fragments in the associated joint space.

4. Monitor for compartment syndrome. Fractures should be splinted and then fixed as soon as possible to minimize chance of further damage.
5. Depressed skull fracture with intraparenchymal bleed, orbital fractures, and concussion.
6. Secondary and tertiary assessments, ongoing.

4 Treatment Strategy

Because of the extent of this 12-year-old's injuries, efficiency in the operating room was paramount. Damage control orthopedics was the goal. Neurosurgery allowed to patient to travel from the PICU for a brief anesthesia time. Therefore, communicating with the operating staff prior to the patient's arrival was critical. The equipment and surgical plan was discussed step by step. A second orthopedic surgeon was available to assist in this case. The femur fracture was addressed with an external fixator. The treatment strategy for fixation of the right foot was to stabilize the medial and lateral columns of the foot and the medial malleolus fracture. There was significant soft tissue swelling, but the foot remained soft with sensation and limited motor function. The medial and lateral columns were realigned and stabilized with k-wires. After fixation, the compartment were soft and were not released intraoperatively. A bulky splint was applied to the lower leg to stabilize. Neurovascular checks were scheduled frequently on the floor with careful monitoring of the foot for compartment syndrome. Post surgery, the neurosurgical team was present at wake up from anesthesia to assess and monitor the patient. Further surgery was planned when patient was stable.

5 Basic Principles

Foot compartment syndrome in the pediatric patient is very rare, and within the literature there are no large series, only small case reports have been published. A meta-analysis that reviewed compartment syndrome in children found that in the current published literature there are only 10 cases or 4% of compartment syndromes in the foot (Lin and Samora 2019). The key to treating foot compartment syndrome is to know the anatomy of the foot and all of the compartments. There are nine compartments of the foot: medial, superficial, lateral, four interosseous, adductor, and calcaneal. One must also consider the other injuries associated with the compartment syndrome and how to successfully treat them be it nonoperative treatment of fractures or operative treatment depending on the bone fractured and the severity.

Compartment syndrome is caused by an increase in pressure, usually from local soft tissue swelling secondary

to injury, in a confined fibrous compartment. Pressure rises to the point where capillary perfusion cannot occur which results in ischemia of the tissues, muscle, nerve within the compartment, which results in fibrosis and subsequent contracture. Of the nine compartments within the foot, the calcaneal compartment is the only hind foot compartment and actually communicates to the deep posterior compartment of the leg. Tibial fractures can cause compartment syndrome of the foot secondary to this connection (Dodd and Le 2013). The medial, superficial, and adductor compartments are along the entire foot length. The lateral and interosseous compartments are only in the forefoot. The basic principles of treating acute compartment syndrome are to release the inelastic tissue confining the compartment to allow perfusion of the soft tissues. Ideally, surgery is performed within 8 h of the onset of compartment syndrome.

Patients with impending compartment syndrome typically present with trauma to the foot resulting in severe soft tissue injury or fracture. A study by Brink et al. reviewed the mechanism of injury leading to acute compartment syndrome of the foot (Brink et al. 2014). They found the most common mechanisms of injury to be motor vehicle accidents and falls. The majority of the patients (22/31) had a fracture of a tarsal bone, 4/31 had a forefoot fracture, and 7/31 had ankle fractures.

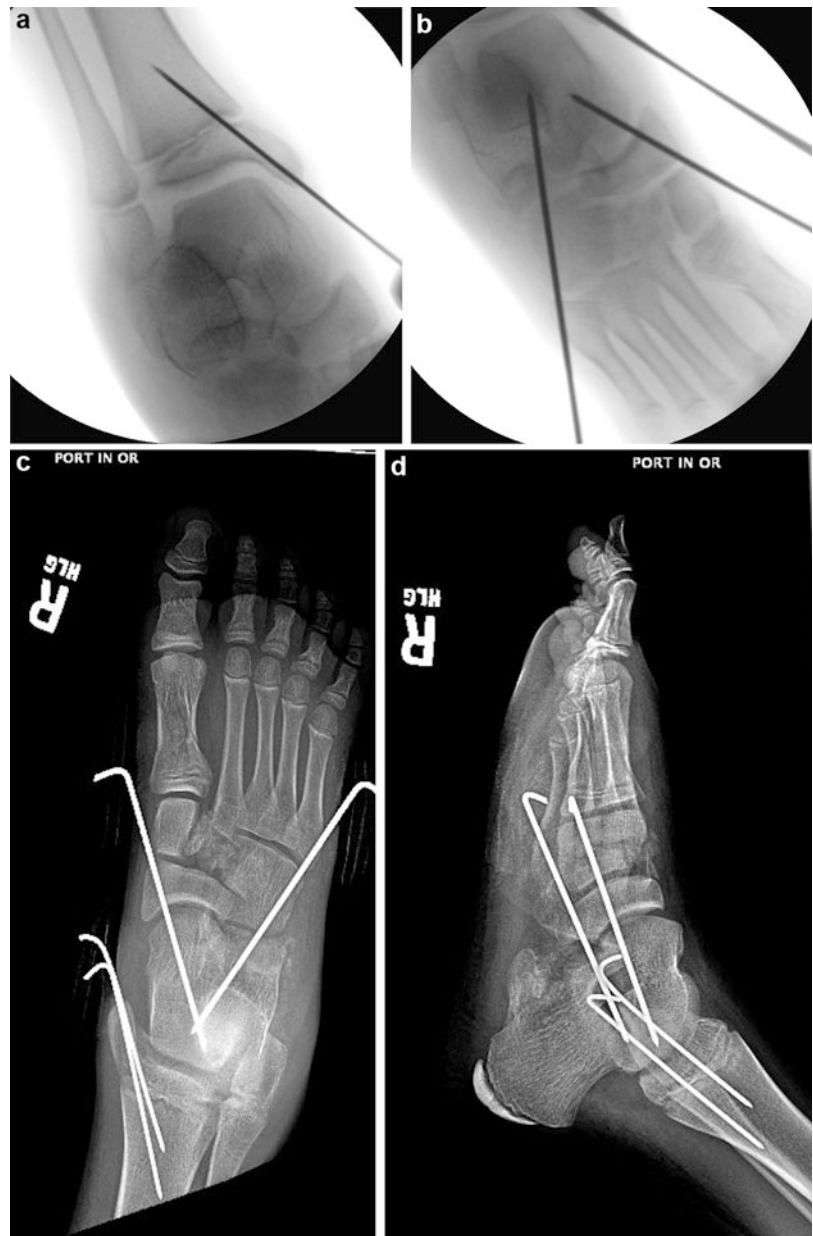
6 Images During Treatment

Approximately 2 weeks later, the patient was taken back to the operating room for definitive treatment of the foot. No paresthesias developed over this interval. He progressively began moving his toes postoperatively. The anterior calcaneus was brought out to length and a reconstruction plate was applied. The middle cuneiform and Lisfranc joints were stabilized with a bridge plate and screw. The femoral external fixator was removed and a submuscular plate was inserted (Fig. 4).

7 Technical Pearls

Measurement of foot compartment pressures can be difficult. The calcaneal compartment tends to increase before other compartments and therefore has higher readings. If compartment pressures are going to be performed at minimum, the calcaneal compartment should be measured. This measurement is performed on the medial side of the foot about 60 mm distal to the tip of the medial malleolus (Dodd and Le 2013). Once the decision to perform decompressive fasciotomies has been made, the patient should be taken emergently to the operating room. Currently, a three incision fasciotomy is

Fig. 4 (a) AP of right ankle after stabilization of medial malleolus fracture. (b) AP of right foot after immediate stabilization of medial and lateral columns. (c) AP of right foot postoperatively. (d) Lateral of right foot postoperatively after immediate stabilization. Note the loss of bone in the anterior calcaneus and soft tissue swelling



recommended. The medial incision is made 4 cm anterior to the posterior aspect of the heel and 3 cm above the plantar surface of the foot, the medial, superficial, and deep central compartments and lateral compartments are all released through this incision. Then two dorsal incisions are made, the first just medial to the second metatarsal and the other just lateral to the fourth metatarsal, the interosseous and adductor compartments are released through these incisions. The skin incisions are closed primarily within 5–7 days. If the wounds cannot be closed primarily, then they often need skin graft coverage.

In this case, definitive treatment of the left femur fracture and foot were planned for approximately 2 weeks after the index surgery to allow for resolution of swelling and to

monitor the brain injury. A submuscular plate was used for the femur fracture to maintain length of the bone and achieve stability. The comminution of the Lisfranc joint and medial cuneiform was reduced and spanned with a bridge plate and Lisfranc screw. The comminution of the anterior calcaneus was addressed with a temporary external fixator to realign the articular surface of the calcaneus which was rotated 90 degrees and achieve length. Next a triphosphate bone graft was placed into the bony void. A mesh plate was used to secure the reduction. The external fixator was then removed. The medial malleolus had been reduced with the initial surgery. He was placed into a bivalved cast and elevated on the floor. Neurovascular checks were again scheduled frequently.

8 Outcome Clinical Photos and Radiographs

See Fig. 5.

9 Avoiding and Managing Problems

Correctly identifying and treating foot compartment syndrome potentially prevents sequela such as chronic pain, foot stiffness, claw toe, hammer toe, and cavus foot

deformity. Claw toes develop due to necrosis of the intrinsic muscles of the foot which no longer function while the extrinsic muscles function well and overpower the toes. Cavus foot deformities result from the scarred plantar structures, which contract and results in the cavus deformity.

The patient recovered from his concussion slowly. The foot healed to be functional but stiff. The hardware on the medial side of the foot was removed secondary to pain. He has not developed a cavus foot deformity, hammer or claw toes deformity. He is able to ride a bike, but running is uncomfortable because of stiffness.

Fig. 5 (a) AP left femur 1 year postop. (b) Lateral left femur 1 year postop. (c) AP right foot postop after healing. (d) Lateral right foot postop after healing. (e) AP right foot after limited hardware removal. (f) Lateral right foot after limited hardware removal



References

- Bibbo C, Lin SS, Cunningham FJ (2000) Acute traumatic compartment syndrome of the foot in children. *Pediatr Emerg Care* 16:244–248
- Brink F, Bachmann S, Lechler P et al (2014) Mechanism of injury and treatment of trauma-associated acute compartment syndrome of the foot. *Eur J Trauma Emerg Surg* 40:529–533
- Dodd A, Le I (2013) Foot compartment syndrome: diagnosis and management. *J Am Acad Orthop Surg* 21:657–664
- Lin JS, Balch Samora J (2019) Pediatric acute compartment syndrome: a systematic review and meta-analysis. *J Pediatr Orthop B*: 1

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